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RADC-TR-80-125, Vol I (of three) (Part 1 of 2)
Final Technical Report
April 1980

AD B049382

MODULAR C^3 INTERFACE ANALYSIS (FLEXIBLE INTRACONNECT)

Martin Marietta Corporation

William G. Bedsole
William F. Kamsler, et al

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ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
Griffiss Air Force Base, New York 13441

This report consists of three volumes. Because of the size of Volume I, it has been divided into two parts. Part 1 contains the basic report and Appendices A through C. Part 2 contains Appendix D.

Volume II, which is classified can be obtained from RADC (DCLT) Griffiss AFB NY 13441.

Volume III contains the Executive Summary.

Volume I of this report references the following classified document:

Modular C^3 Interface Analysis (Flexible Intraconnect), Volume II, Considerations (U) dated October 1979, SECRET.

RADC-TR-80-125, Volume I (of three) Part 1 of 2 has been reviewed and is approved for publication.

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(19) TR-80-125-VOL-1-PT-1

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (18) RADC-TR-80-125, Vol I (of three) Part 1 (of two)	2. GOVT ACCESSION NO. AD-B049 382L	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) MODULAR C^3 INTERFACE ANALYSIS (FLEXIBLE INTRACONNECT). Volume I, Part 1.		5. TYPE OF REPORT & PERIOD COVERED (9) Final Technical Report, Oct 77 — Jul 79
		6. PERFORMING ORG. REPORT NUMBER (14) MCR-79-1411-VOL-1-PT-1
7. AUTHOR(s) (10) William G. Bedsole, Lennet Baxter, William F. Kamsler, ~~et al~~ James Billard, James Burk		8. CONTRACT OR GRANT NUMBER(s) F19628-77-C-0262
9. PERFORMING ORGANIZATION NAME AND ADDRESS Martin Marietta Corporation, Denver Division, PO Box 179, Denver CO 80201		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 63789F (16) 23170102 (17) 01
11. CONTROLLING OFFICE NAME AND ADDRESS Rome Air Development Center (DCLT), Griffiss AFB NY 13441		12. REPORT DATE (11) April 1980
		13. NUMBER OF PAGES 403
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Same (12) 402 (15) F19628-77-C-0262		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A

16. DISTRIBUTION STATEMENT (of this Report)

Distribution limited to U.S Government agencies only; test and evaluation; April 1980. Other requests for this document must be referred to RADC (DCLT), Griffiss AFB NY 13441.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Same

18. SUPPLEMENTARY NOTES

RADC Project Engineer: James L. Davis (DCLT)
This report was prepared in parallel with a separate Flexible Intraconnect design definition study conducted by Hughes Aircraft Company under F19628-77-C-0261, work unit 23170101. (see reverse)

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Time Division Multiple Access	Fiber Optics
Data Communications	Data Bus Communications
Local Communications Networks	Tactical Command and Control
Network Protocols	Command, Control and Communications
Data Transmission	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report documents the preliminary design for a high capacity wide-band general purpose data/communications busing system. The bus, called a "Flexible Intraconnect," will be used to achieve modularity in the design, implementation and deployment of command, control and communications (C^3) centers of the Tactical Air Force (TAF). FI design requirements were established by estimates of traffic loads for current and future (through 1980) configurations of Tactical Air Control System

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(TACS) C^3 centers of the TAF. Surveys of data distribution system architectures, current and developing technologies, and device interfaces are provided. A design of a Flexible Intraconnect having high transmission rate and capacity, positive flow control and configuration flexibility is described. A standardized interface for physical and functional device to bus access is described. Description of the major functional elements of the FI are provided along with top level block diagnosis. The design was analyzed and preliminary estimates of error performance, reliability, capacity and response times were developed.

Block 18 cont'd

This report consists of three volumes. ~~Because of the size of~~ Volume I, ~~it has been divided into two parts.~~ Part 1 contains the basic report and Appendices A through C. Part 2 contains Appendix D.

Volume II, which is classified can be obtained from RADC (DCLT) Griffiss AFB NY 13441.

Volume III contains the Executive Summary.

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PREFACE

This report has been prepared by the Martin Marietta Corporation for the Communications and Control Division of the Rome Air Development Center in accordance with Contract F19628-77-C-0262. The work reported herein consists of Task I, Task II, and Task III of Phase I of an on-going study being conducted by the Air Force to develop a Flexible Intraconnect for tactical C^3 equipment connectivity.

As evidenced by the quantity of analyses performed and documented during the period of this study, many individual specialists contributed significantly toward achievement of these results. Martin Marietta personnel who participated in this study were:

William F. Kamsler - Task III Project Manager
William Bedsole - Task I and II Project Manager

Dr. Denmer Baxter
James Billars
James Burrill
Esther Connors
Rose Cress
William Dudley
Richard Endicott
Linda Fulmer
Lenard Funck
Roy Gilbreath
James Hayne
John Hebel
W. Raymond Herbert
Louis Horkan
Joel Horrell
James Jones
Cameron MacDonald
Chris Martinson
George McClure
Louise McFadden
Peter Miller
Douglas Noden
Christian Pfitzer
Howard Ritchie
William Robertson
David Sully
William Tyrlick

During the course of the study, the contractor received excellent support from many Government offices in obtaining background documents and information required for completion of the analyses. A particular note of appreciation is expressed to the following persons:

James Davis, RADC
David Griffith, RADC
John McLean, RADC
Walter Lee, MITRE
Major Robert Riopelle, TAFIG
Capt. Jon Campbell, TAFIG
Wayne Chauffe, AFCSC
Robert Carto, NSA

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ABBREVIATIONS AND ACRONYMS

AADCP	Army Air Defense Command Post
ABCCC (ABCC)	Airborne Battlefield Command and Control Center
AC	Airspace Control
ACH	Army Command Headquarters
ACIC	Automated Combat Intelligence Center
ACK	Acknowledge
ACM	Air Conditioning Module
AC&W	Aircraft Control and Warning
A/D	Analog-to-Digital
ADCCS	Army Air Defense Command and Control System
ADL	Automatic Data Link
ADP	Automatic Data Processing
AEM	Ancilliary Equipment Module
AFCC	Air Force Component Commander
AFCH	Air Force Component Headquarters
AFGWC	Air Force Global Weather Central
A/G	Air-to-Ground
ALCC	Airlift Control Center
ALCE	Airlift Control Element
APD	Avalanche-Photo Diode
ARM	Antiradiation Missile
ART	Automatic Radar Tracking
AS	Air Surveillance
ASIT	Adaptable Surface Interface Terminal
ASRT	Air Support Radar Team
ATRC	Air Traffic Regulation Center
AWACS	Airborne Warning and Control System
BC	Bus Controller
BCD	Binary Coded Decimal
BCS	Bus Control Station
BER	Bit Error Rate

BP	Block Parity
BPSK	Binary Phase - Shift Keying
b/s	bits per second
C^3	Command, Control, and Communications
CATV	Cable Television
CCT	Combat Control Team
CIC	Combat Intelligence Center
CM	Console Module
C/N	Carrier to Noise (ratio)
CNCE	Communications Node Control Element
codec	Coder/Decoder
COMSEC	Communications Security
CONUS	Continental United States
COS	Complementary Symmetry
CP	Command Post Communications Processor
CPU	Central Processing Unit
CRC	Control and Reporting Center
CRF	Channel Reassignment Function
CRP	Control and Reporting Post
CSCE	Communications Systems Control Element
CSPE	Communications System Planning Element
CVSD	Continuously Variable Slope Delta
DA	Data Adapter
DASC	Direct Air Support Center
dB	Decibel
DCF	Drone Control Facility
DCG	Digital Communications Group
DCR	Digitally Coded Radar
DCS	Defense Communications System
DC/SR	Display and Control/Storage and Retrieval
DDL	Digital Data Link
DLED	Dedicated Loop Encryption Device
DMA	Direct Memory Access

DNVT	Digital Nonsecure Voice Terminal
DP&D	Data Processing and Display
DPM	Data Processing Module
DRE	Display Remoting Enhancement
DSCS	Defense Satellite Communications System
DST	Data Source Terminal
DSVT	Digital Subscriber Voice Terminal
DTMF	Dual-Tone Multiple Frequency (Switch Signaling)
ECCM	Electronic Counter-Countermeasures
ECL	Emitter-Coupled Logic
ECM	Electronic Countermeasures
ELINT	Electronic Intelligence
EM	End of Medium
EMI	Electromagnetic Interference
EMP	Electromagnetic Pulse
EMR	Electromagnetic Radiation
ERU	Emergency Reaction Unit
ESD	Electronic Systems Division
ETB	End of Transmitted Block
ETX	End of Text
EW	Electronic Warfare
FAC	Forward Air Controller
FACP	Forward Air Control Post
FARS	Forward Area Radar System
FAX	Facsimile
FDM	Frequency Division Multiplexer
FEBA	Forward Edge of the Battle Area
FLIR	Forward-Looking Infrared
F/O	Framing and Overhead
FRAG	Fragmentary
FRRP	Forward Reconnaissance Reporting Post
FSK	Frequency Shift Key
FY	Fiscal Year

G/A	Ground-to-Air
G/A/G	Ground-to-Air-to-Ground
GCC	Ground Control Central
GDM	Group Display Module
GDU	Graphic Display Unit
G/G	Ground-to-Ground
GHz	Gigahertz
GM	Group Modem
GTSSC	Ground Target Surveillance and Strike Control
HF	High Frequency
HF/SSB	High Frequency/Single Sideband
Hz	Hertz
ID	Identification
IDR	Identification Resource
IF	Intermediate Frequency
IFF	Identification - Friend or Foe
IIS	Imagery Interpretation Segment
IITS	Intratheater Imagery Transmission System
IL	Injection Laser
IMPATT	Impact Avalanche Transit Time
INTACS	Integrated Tactical Communications System
I/O	Input/Output
IR	Infrared
JANAP	Joint Army, Navy, Air Force Publication
JCS	Joint Chiefs of Staff
JTF	Joint Task Force
JTFWC	Joint Task Force Weather Center
JTIDS	Joint Tactical Information Distribution System
JTFWECEN	Joint Task Force Weather Center (JTFWC)
kb/s	Kilobits Per Second
KDPP	Keyboard/Display/Printer/Punch
KG	Key generator
KPP	Keyboard/Printer/Punch
KSR	Keyboard Send/Receiver

kw/s	Kilowords Per Second
LED	Light-Emitting Diode
LGM	Loop Group Multiplexer
LOS	Line of Sight
LSDI	Large-Screen Display Indicators
LSI	Large-Scale Integration
MAC	Military Airlift Command
MACCS	Marine Air Command and Control System
MARRES	Manual Radar Reconnaissance Exploitation System
Mb/s	Megabits Per Second
MDEU	Manual Data Entry Unit
MDT	Mobile Data Terminal
MHz	Megahertz
μs	Microsecond
MMW	Millimeter Wave
MPC	Message Processing Center
MPM	Message Processing Module
MPP	Microprogrammable Processor
MRS[3]	Multilateration Radar Surveillance Strike Subsystem
MRTT	Modular Record Traffic Terminals
ms	Milliseconds(s)
MTBF	Mean Time Between Failures
MTI	Moving Target Indicator
MTTR	Mean Time To Repair
MUX/SYNC	Multiplexer/Synchronizer
MUX/DEM	Multiplexer/Demultiplexer
Mw/s	Megaword Per Second
NA	Numerical Aperture
NADGE	NATO Air Defense Ground Environment
NAK	No-Acknowledge
NMOS	N-Channel Metal Oxide Semiconductor
NRZ	Nonreturn-to-Zero
NSA/CSS	National Security Agency/Central Security Service

NTDS	Naval Tactical Data System
OHF	Off-Hook Factor
O&M	Operation and Maintenance
OPS	Operations Central
O&S	Operation and Support
PF	Peakedness Factor
PIN	Positive-Intrinsic-Negative (diode)
PLSS	Position Location Strike System
PM	Preventive Maintenance
PMSV	Pilot-to-Metro Service
p-p	Peak-to-Peak
PPI	Planned Position Indicator
PPIF	Photo Processing Interpretation Facility
PSK	Phase-Shift Keying
PU	Participating Unit
PWP DIV/COMB	Power Divider/Combiner
QPSK	Quarature Phase-Shift Keying
QSR	Quick-Strike Reconnaissance
RADC	Rome Air Development Center
RAM	Random Access Memory
RAWIE	Radio Weather Intercept Element
R&D	Research and Development
RF	Radio Frequency
RMC	Remote Multiplexer Combiner
rms	Root Mean Square
ROM	Read-Only Memory
RPV	Remotely Piloted Vehicle
RRP	Reconnaissance Reporting Post
RZ	Return to Zero
SCC	System Configuration Concept
SDM	Space-Division Multiplex
SEL	Select
SF	Single Frequency
SGT	Satellite Ground Terminal

SHF	Super High Frequency
SI	Special Intelligence
SIF	Selective Identification Feature
SIGINT	Signals Intelligence
SLR	Side-Looking Radar
SNR	Signal-to-Noise Ratio
SOH	Start of Header
SOS	Silicon on Sapphire
SRP	Sensor Reporting Post
SRWBR	Short-Range Wideband Radio
SSB	Single Sideband
STX	Start of Text
SYSCON	System Control
TA	Tactical Airlift
TAB	Tactical Air Base
TABWE	Tactical Air Base Weather Element
TABWS	Tactical Air Base Weather Station
TAC	Tactical Air Command
TACC	Tactical Air Control Center
TACCWE	Tactical Air Control Center Weather Element
TACP	Tactical Air Control Party/Post
TACS	Tactical Air Control System
TADIL	Tactical Digital Information Link
TAF	Tactical Air Force
TAFC	Tactical Air Force Commander
TAFIG	Tactical Air Forces Interoperability Group
TAFIIS	Tactical Air Forces Integrated Information System
TAIS	Tactical Air Intelligence System
TAOC	Tactical Air Operations Center
TAR	Tactical Air Reconnaissance
TATCF	Terminal Air Traffic Control Facility
TAWAC	Tactical Airborne Weather Analysis Center
TCC	Technical Control Center
TCF	Technical Control Facility

TCCF	Tactical Communications Control Facility
TDF	Tactical Digital Facsimile
TDM	Time-Division Multiplex
TDU	Tabular Display Unit
TEREC	Tactical Electronic Resonnaissance
TERPE	Tactical Electronic Reconnaissance Processing and Evaluation
TGM	Trunk Group Multiplexer
TIDP	Technical Interface Design Plan
TIPI	Tactical Information Processing and Interpretation
TOBWE	Tactical Observing Weather Element
TOC	Tactical Operations Center
T/R	Transmitter-Receiver
TRI-TAC	Joint Tactical Communications Program
TTL	Transistor-Transistor Logic
TTSA	Tactical Traffic and System Analysis
TTY	Teletypewriter
TUCP	Tactical Unit Command Post
TUOC	Tactical Unit Operations Center
TV	Television
TWAC	Tactical Weather Analysis Center
TWC	Tactical Weather Center
TWR	Tactical Weather Radar
TWS	Tactical Weather System
UHF	Ultrahigh Frequency
ULS	Unit Level Switch
UME	Unformatted Message Element
USAF	United States Air Force
VHF	Very High Frequency
VMOS	Vertical Metal Oxide Semiconductor
WGS	Weather Graphics System
WWMCCS	Worldwide Military Command and Control System

EVALUATION

Command and control capabilities for the Tactical Air Force take too long to develop, do not satisfy the intent of original requirements, cost too much, can't adapt to simple changes in procedures and fail to interoperate with other systems. This is caused, in part, by the acquisition process itself where each system is built as a unique specialized package with tightly specified parameters that meet specific (but highly volatile) mission requirements in a very explicit way. The resulting designs become over-optimized, needlessly complicated and have little potential for growth and evolutionary capabilities.

This contract effort represents an important step toward simplifying the connectivity among the aggregation of communications and data processing devices that constitute a command and control system. The Flexible Intraconnect architecture will permit rapid evolution of C^2 capabilities and timely introduction of new functions, improved procedures and technological advances. The FI is intended for immediate application to reduce complexities of existing C^2 centers and will simplify the architecture of systems for future centers, while absorbing greater volumes of information associated with increasing levels of automation.

The results of this contract are being incorporated in specifications for a program to develop equipment and software, verify technical performance and demonstrate operational advantages and suitability. This work is under the Distributed C^2 (R3C) thrust of the Communications and Information Processing for C^2 (RA3) section of the RADC Technology Objectives and Plans (TO&P) structure.

JAMES L. DAVIS
Project Engineer

1.0 INTRODUCTION

This report describes the results of Modular C^3 Interface Analyses performed by Martin Marietta Corporation from October 1977 through April 1979 on a study contract to define a Flexible Intraconnect (FI) capability for tactical command, control, and communications (C^3) facilities.

This final report presents the results of analyses performed in Tasks I, II, and III of the contract. Task I analyses are detailed in Martin Marietta Corporation Report OR 15,042 and Task II in MCR-78-1416.

A Flexible Intraconnect is defined as a common transmission facility that may be accessed by all communications and automatic data processing devices for the transfer of information between these devices within a center. A center is a facility such as the Tactical Air Control Center (TACC) and the Control and Reporting Center (CRC) (Fig. 1-1) where a concentration of C^3 equipments are deployed to support air operations.

1.1 FI objectives.

The objective of the study was to conceptually design a Flexible Intraconnect capability for tactical C^3 facilities which provides operational users with the flexibility to configure for current and future requirements. This intraconnect would become the foundation of a long-term Air Force effort to develop and field tactical modular C^3 facilities. Its design emphasizes modularity, interoperability, interconnectivity, flexibility and survivability. The design supports information exchange between tactical C^3 facilities when C^3 equipments and employment concepts evolve from those currently used to those which may exist in the year 2000. The design concept does not compromise the functional relationships and operational procedures employed in systems using equipment of the 407L *Tactical Air Control Systems*, 428A *Tactical Information Processing and Interpretation System*, or in the 433L *Weather Observing and Forecasting System*. The conceptual design is compatible with the architectures of the DCS, WWMCCS, TRI-TAC, and other systems currently under development such as JTIDS and 485L *Tactical Air Control System Improvements* (TACSI).

The design is capable of expansion and growth to accommodate evolving concepts such as computer resource sharing, distributed data base/management, packet switching, bus concepts, information distribution, radar netting, modular operations centers, and geographically distributed functions.

The proposed design meets objectives for a wideband Flexible Intraconnect for Tactical Air Force modular C^3 facilities and is suitable for deployment either in a static theater environment or a highly mobile situation.

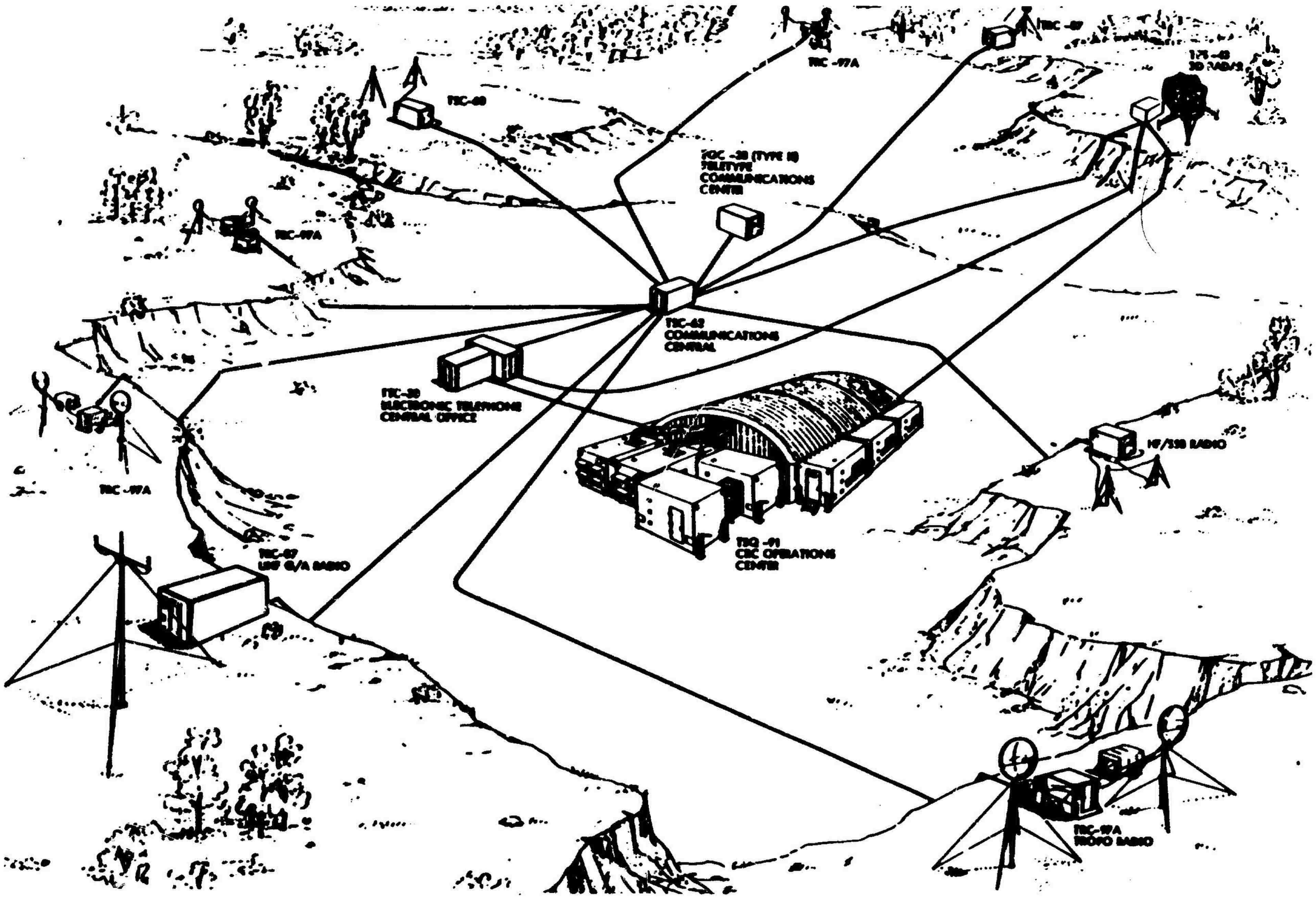


Figure 1-1 Control and keporting Center.

1.2 Background.

Tactical users in C^3 equipment centers have recognized the need to improve methods for interconnecting equipment in these highly populated facilities. The most common problems associated with the current intraconnect method, using multiconductor cable, may be summarized as:

a. Poor reliability, primarily due to connector failures;
b. Weight and size of cable harnesses;
c. Excessive setup and teardown times;
d. Inability to change a center's configuration;
e. Inability to convert incompatible interface characteristics to allow compatible interoperation between dissimilar devices;
f. Inability to permit peripherals at remote locations to access the central processing unit (CPU) data base;
g. Inability to upgrade the automatic data processing (ADP) system by substitution of a single device such as the CPU without reengineering the intraconnect for the entire ADP system and replacement of many of the peripherals; and
h. Security intrusion problems.

In addition, recent studies have shown significant cost savings can be realized through adoption of a family of standard ADP devices with standard software options that can be used in all TAF equipment requiring those functions. The objective is to minimize proliferation of ADP equipment types and software designs in the inventory. An important step in achieving this standardization is the adoption of a common set of interface characteristics for future ADP developments. It is also important to provide compatible interfaces between current inventory devices, those soon to be fielded, and those to be developed in accordance with the new standard. Initially, the new intraconnect must accommodate a variety of interface characteristics by providing compatibility conversions to match the characteristics of the common standard. Future ADP devices will be designed with input/output (I/O) characteristics in accordance with this standard.

The Air Force began studies of the feasibility of a Flexible Intraconnect in 1974. The results are summarized in Appendix A of the Task I report.

1.2.1 Task I. This task's efforts were directed towards:

a. Defining user requirements for the Flexible Intraconnect; and
b. Selecting the preferred design concept for implementation of the Flexible Intraconnect.

The analysis addressed the problem of information transfer within a center, i.e., intrashelter and intracenter. Design technique investigations were performed at the level of detail necessary to compare the cost-effectiveness of candidate concepts.

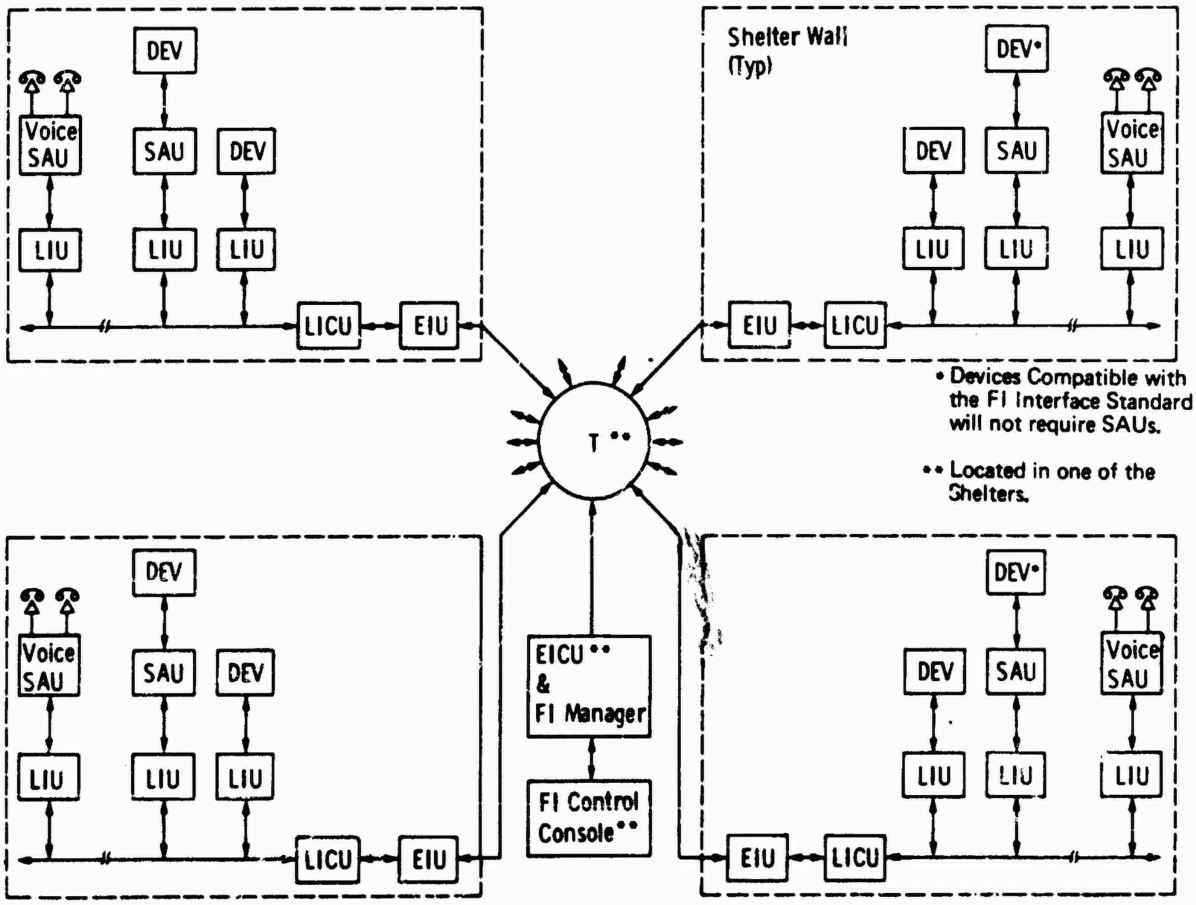


Figure 1-2. Implementation of recommended system.

Analysis efforts have concentrated on design characteristics of the local intraconnect; the point of interface with C^3 devices and the application of the Interface Standard. Figure 1-3 shows the open-loop topology of the local intraconnect. The local intraconnect bus consists of a forty twisted-pair ribbon cable looped between communication and ADP devices within a shelter. Data transfer is in parallel at a 5 Mb/s rate. Devices access the intraconnect by means of an LIU. The device side of the LIU will be designed to meet the characteristics of the Interface Standard. If the device I/O interface characteristics are compatible with this Interface Standard, the device may be connected directly to the LIU. If not, the necessary compatibility conversions are performed by an adapter module. LIU access to the local intraconnect bus is controlled by the Local Intraconnect Control Unit (LICU). Sixty-four LIUs can be serviced on the local intraconnect. The LICU polls each LIU in sequence to coordinate data transmission onto the bus in formatted message blocks.

The requirements analyses examined the operational scenarios of C^3 equipment the Flexible Intraconnect must support, and provided quantification of traffic flow for both communications and ADP traffic within each of ten equipment center types. Maximum traffic load for a local intraconnect within an equipment shelter was estimated to approach 150 Megabits per second (Mb/s). Maximum traffic load for the external intraconnect between shelters was also estimated to approach 150 Mb/s.

The recommended FI concept provides a two-level intraconnect, i.e., one level for local (intrashelter) traffic, and another for external (intracenter) traffic. The local intraconnect employs a conventional open-loop topology using forty twisted-pair ribbon cable for transmission; TDM-SDM for channelization, and sequential polling for user access.

The external intraconnect imploys a star topology using multi-channel fiber optic cable for transmission, TDM-SDM for channelization, and sequential polling for access control.

A three-phase implementation plan was suggested to permit incremental funding of development costs for the intraconnect, while providing intraconnect capabilities compatible with the requirements of the incremental evolution of C^3 equipment.

1.2.2 Task II. This task's efforts were directed towards:

a. Analyzing the interface characteristics of inventory and future C^3 devices that interface with the Flexible Intraconnect;
b. Performing a functional design of the C^3 device-to-Flexible Intraconnect interface;
c. Preparing a Preliminary Interface Standard document to establish a design standard for the C^3 device-to-Flexible Intraconnect interface; and
d. Verifying the capability of the Flexible Intraconnect Concept to satisfy the intraconnect requirements of the revised TAFIIS Master Plan.

The interface characteristics of all communications and ADP equipments expected to access the intraconnect were compiled and analyzed to determine the device-to-Local Intraconnect Unit (LIU) interface requirements. Existing interface standards were studied to determine similarities with the requirements identified for the device-to-LIU interface. At the same time, analyses were performed to further define the functional operation of the LIU, identify the characteristics of the LIU-to-Local Intraconnect (LI) interface, and to perform a preliminary functional design of the LIU and the adapters. Outputs of these subtasks enabled selection of characteristics for the interface standard to be applied at the point of interface between the LIU and the ADP or communications device. A Preliminary Interface Standard document was prepared to describe the characteristics of the recommended interface.

A concept verification effort was performed confirming that the recommended Flexible Intraconnect concept will satisfy the intraconnect requirements of the C^3 equipment scenario defined in the revised TAFIIS Master Plan.

1.2.3 Task III. This task's efforts were directed towards:

a. Preliminary design of the intraconnect scheme and the subnetwork bus configurations;
b. Communication network implementation;
c. Development of message structure, protocols and formats;
d. Network control and resource management;
e. Security aspects relative to TEMPEST effects, intrusion, and eavesdropping; and
f. Reliability, maintainability, and availability analyses.

The preliminary design study details operational facets of the FI and shows how recommended architecture handles point-to-point, virtual bus, lazy susan, and broadcast messages.

Control functions via the FI Manager were examined and message structure, protocols and header formats were detailed. The interconnection of communication devices and their interface with other common-user communications were conceptually designed. Alternate configurations were presented to time phase communications into the FI.

Design of encryption/decryption devices into the FI to meet security requirements were thoroughly investigated. Estimates were made regarding the FI system's utility to determine the redundancy that must be incorporated in the design to assure availability.

1.3 Summary.

The recommended Flexible Intraconnect concept employs a two-level bus transmission system. The local intraconnect bus carries the intrashelter traffic. Figure 1-2 shows the configuration for this concept as envisioned for employment in C^3 equipment centers. The external intraconnect bus carries the intracenter traffic. This bus consists of multi-channel fiber optic cables arranged in a star topology to connect each equipment shelter with a centrally located fiber optic transponder with as many as 63 legs in the star configuration. Access to the external intraconnect from a local intraconnect is controlled by the External Intraconnect Control Unit (EICU). Multiplex and modem functions for interfacing between the external and local intraconnects are performed in the External Intraconnect Unit (EIU).

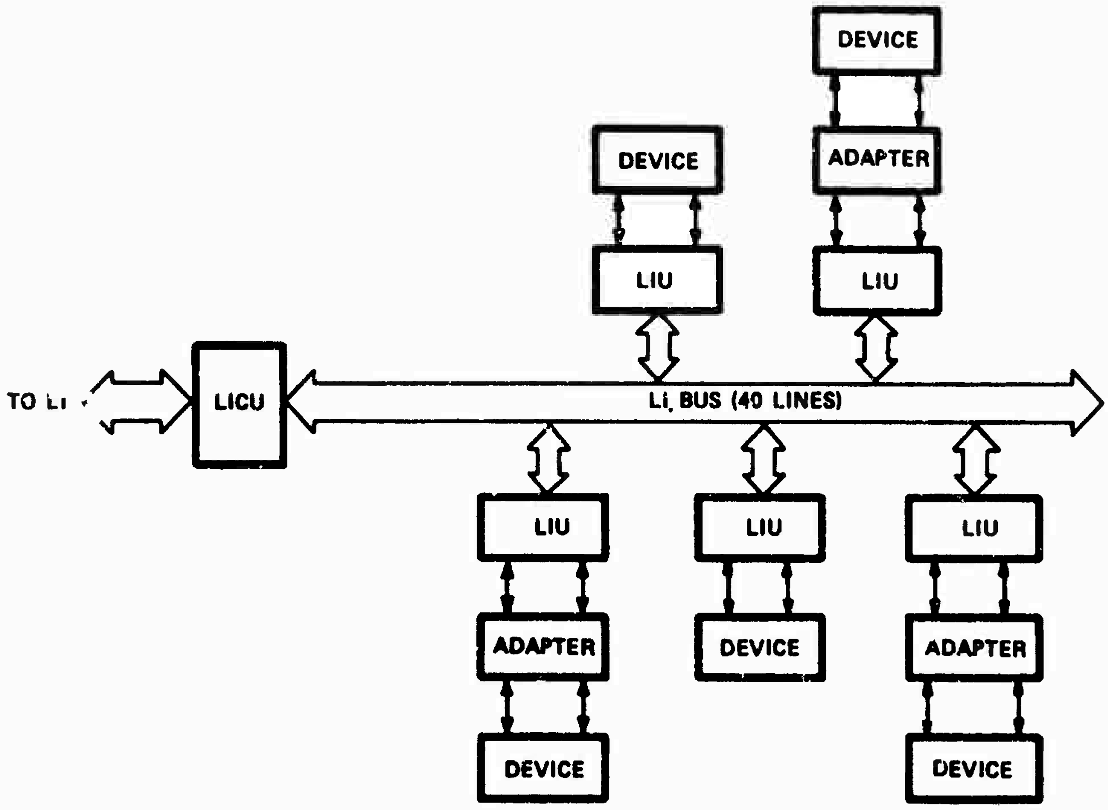


Figure 1-3. Local Intraconnect.

The external intraconnect uses a star topology. This concept provides an efficient means of transmitting data throughout the center. Figure 1-4 shows the external intraconnect bus configuration for a Control and Reporting Center (CRC). This concept was selected over others for its capacity, compatibility, flexibility, security, and growth characteristics. Forty pairs from the LICU with 5 Mb/s parallel data on each are multiplexed onto four fiber optic wave guides in the EIU. Each wave guide handles 50 Mb/s data. The EIU thus performs data conversion and electrical-to-optical transition. The EIU multiplex is shown in Figure 1-5 .

The proposed External Interface, providing communications between shelters, uses fiber optic cables as the transmission means. Fiber optics were selected for the following reasons:

a. Wide bandwidth;
b. Negligible crosstalk;
c. No common-mode or ground-loop problems;
d. Cable impervious to EMP or lightning disruption;
e. Fastest service restoration;
f. High-link availability;
g. Smallest size, lowest weight of all candidates;
h. Lowest cost alternative now, with further cost reductions in prospect; and
i. Minimal security intrusion problems.

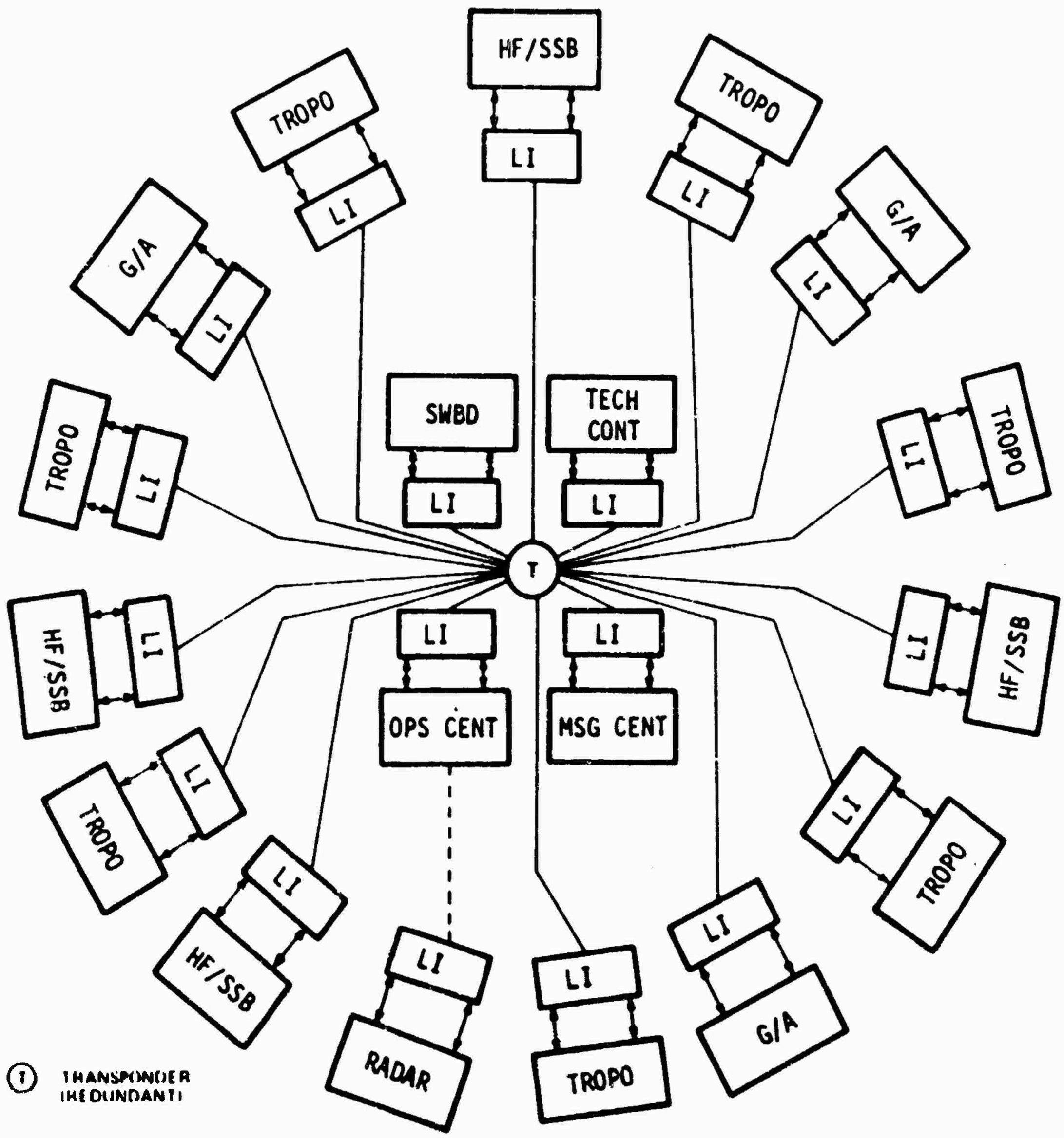


Figure 1-4. External intraconnect topology.

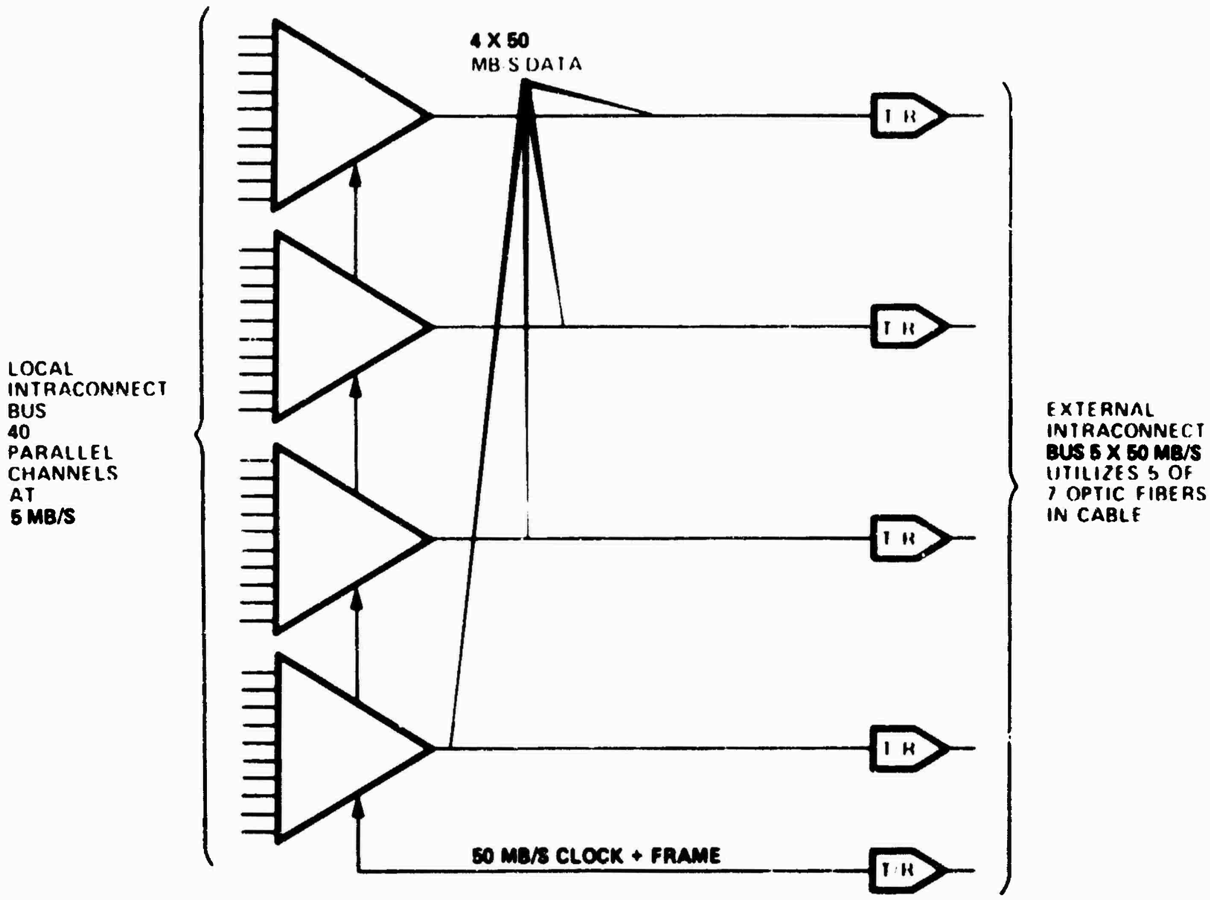


Figure 1-5. External intraconnect unit.

The External Interface will intraconnect up to a total of 63 LICUs.

Considerable work has been done on the development of data transfer protocols. Protocols to control data transmission over the FI have been defined for all levels of communication. The overall view of data transmission control can be seen in Figure 1-6. The characteristics of data transmission on the FI can be described in both functional and operational terms. Figures 1-7 and -8 show the five different layers of protocol affecting data flow over the FI.

a. FI Level A concerns user-to-user protocol, i.e., process control. This data transfer control governs activities between devices as if they were directly connected.
b. FI Level B pertains to the formatting of address, control, and data to and from a DTE for interface to other DTEs. This protocol is mainly for control between adapters and would disappear when adapters are no longer needed.

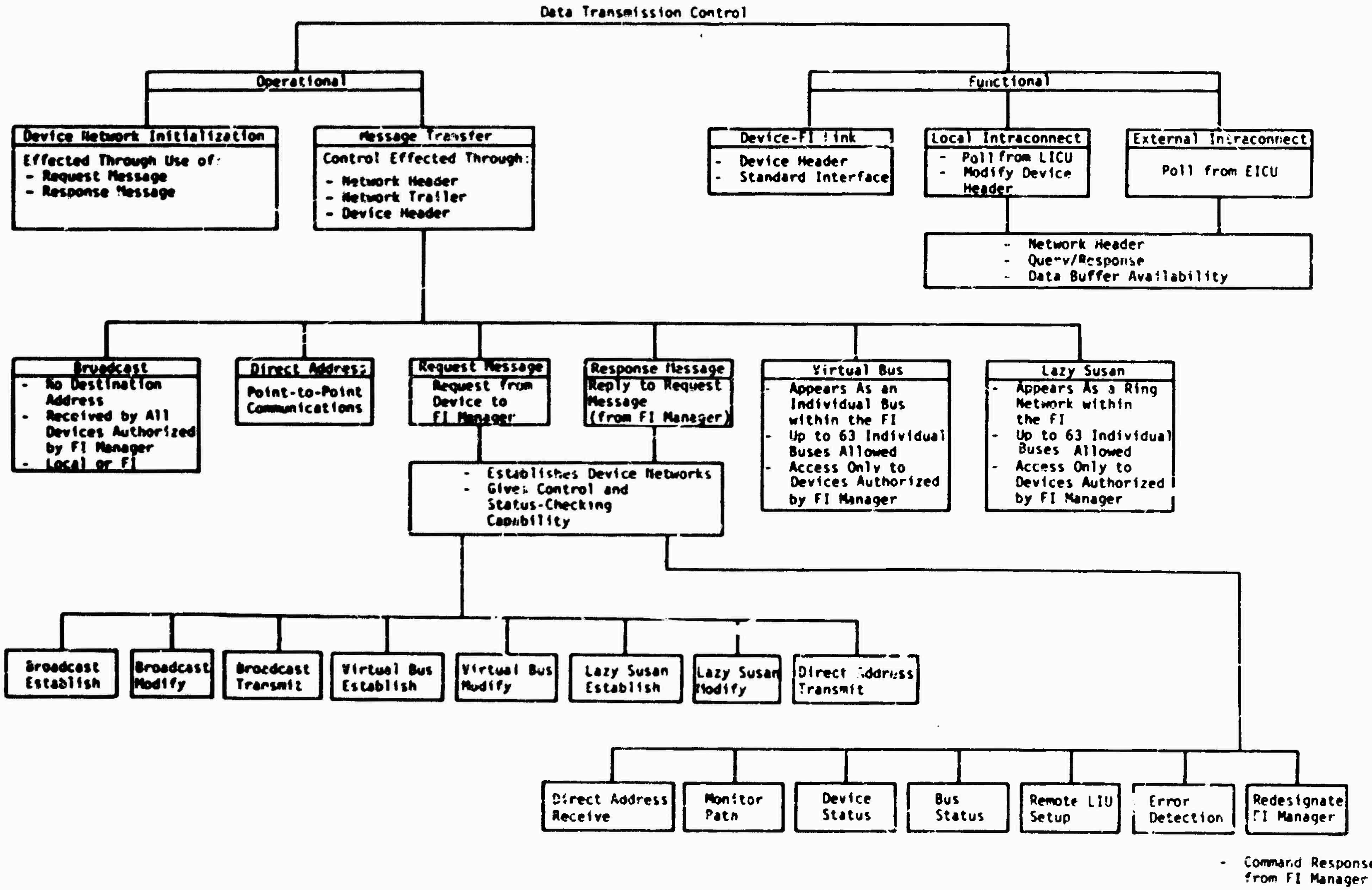


Figure 1-6. Data transmission control.

The following three layers of protocol combine to perform end-to-end data transmission between users on the FI. They are unique to the FI.

c. FI Level C concerns the data link between a DTE or SAU and the FI. Control information for operation on the FI is contained in a device header which is attached to a block of data by the DTE or DAU.

d. FI Level D consists of the LI control. A network header and trailer are added to the device header and data block by the LIU. This provides information required to control LIU-LIU and LIU-LICU data transfers.

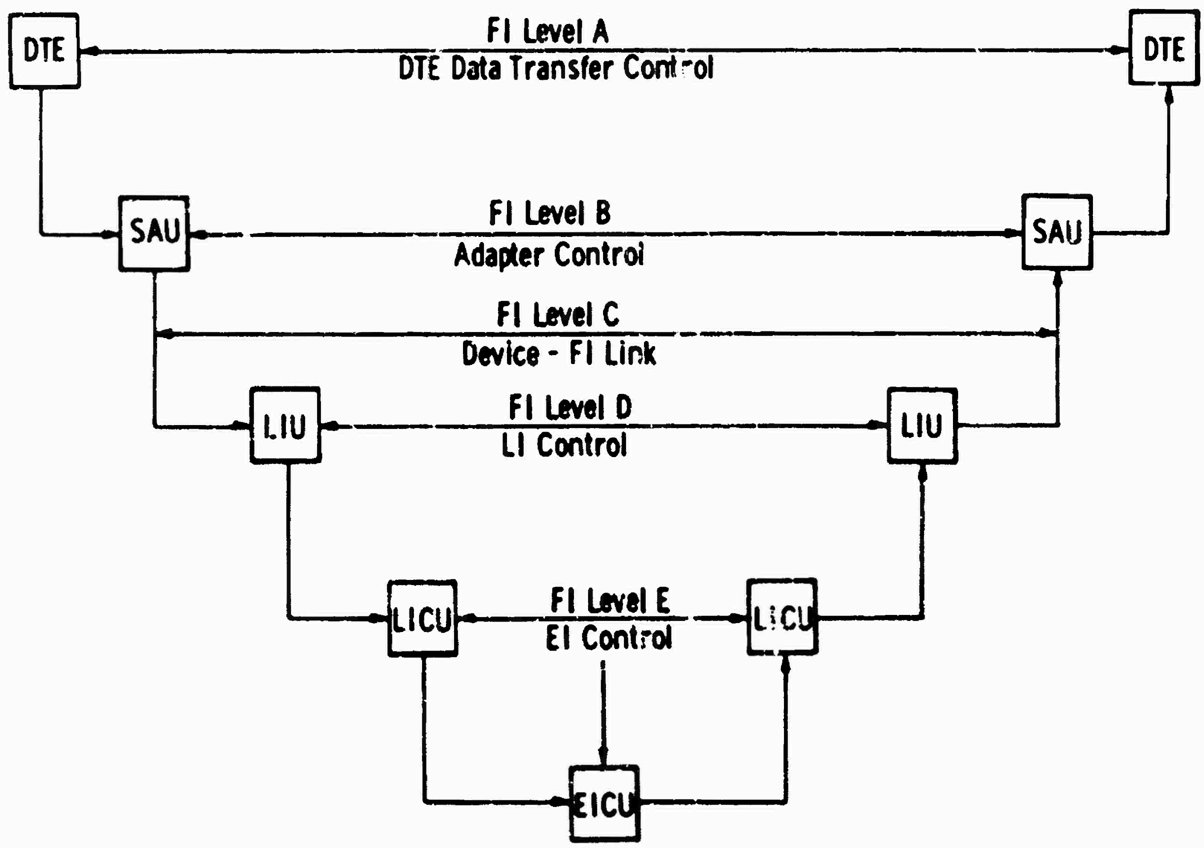


Figure 1-7. Levels of protocol.

e. Data transfer on the EI continues using the network header and trailer formulated at FI Level D. However, communication between the EICU and EIUs is required to configure the FI into a proper mode of operation. This warrants a separate layer of protocol - FI Level E - which pertains to the FI control. FI levels D and E are transparent to the user.

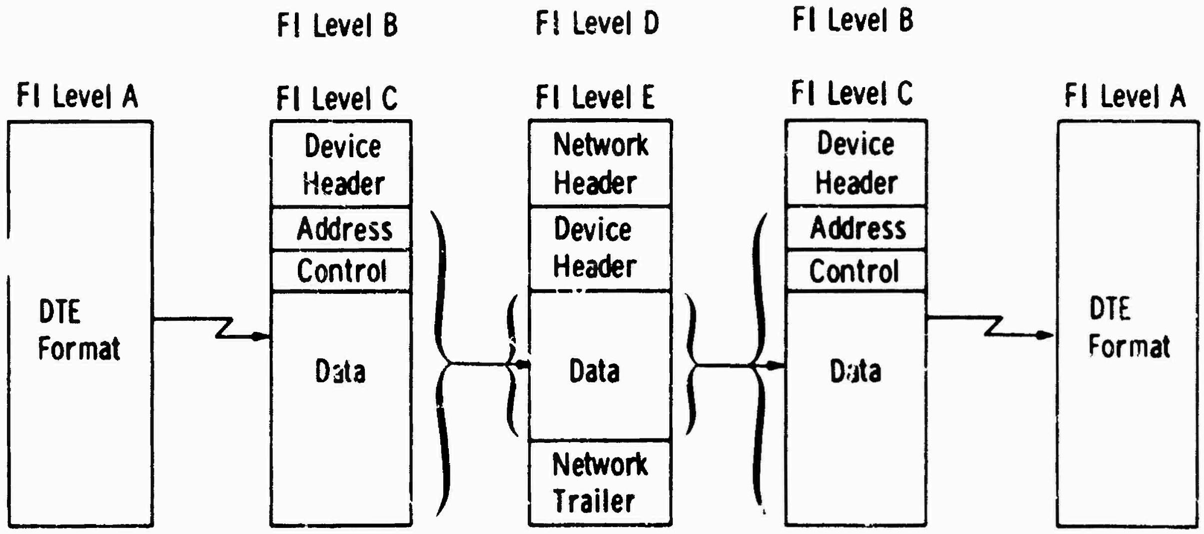


Figure 1-8. Formats at each FI level.

1.4 Concerns.

This report details the work done in the design of the Flexible Intraconnect capability. This section describes several concerns left unresolved due to time and budget constraints.

1.4.1 Digital telephones. The method for encoding voice traffic for transmission on the FI is currently under evaluation. The candidates are eight-bit pulse code modulation (PCM) encoding vs continuously variable-slope delta moudlation (CVSD). Eight-bit PCM encoding requires 64 kb/s per channel whereas CVSD requires 32 kb/s with a future possibility to use 16 kb/s. The primary reason for considering CVSD is its interface compatibility with the TRI-TAC system, which uses CVSD exclusively. PCM, however, has advantages in certain telephone operations such as conferencing due to its linear companding characteristics, and the possibility of future bandwidth reduction by evolution to linear predictive coding (LPC).

1.4.2 Full-duplex transmission on the EI. The EI will use multichannel fiber optic wave guides in a star configuration to route data between TAF shelters. As envisioned, separate links will be provided to and from a shelter with the data sent simplex. Consideration should be given to implementing a full-duplex communication system on a single channel set of fiber optics.

1.4.3 Star coupler. The proposed system uses an active electronic star coupler to receive data from any one of 63 EIUs and transmit to all EIUs. With the maturing of fiber optic technology, it will become practical to use a passive fiber optic star coupler as the transponder.

1.4.4 High-speed data transmissions on the EI. Traffic analyses indicate a requirement for 200 Mb/s transmissions between TAF centers. State-of-the-art investigations of fiber optic technology suggest a maximum transmission rate of 50 Mb/s per optic fiber. Accordingly, the preliminary design multiplexes the 200 Mb/s data onto four fiber optic wave guides. As fiber optic technology matures, consideration should be given to using the high theoretical bandwidth of fiber optics to transmit and receive data on a single wave guide.

1.4.5 Transmission security. One of the reasons for the selection of fiber optics as the medium for transmitting data between TAF shelters was the lack of vulnerability to tampering, breach of privacy, and intentional or unintentional jamming. However, to meet present COMSEC requirements, encryption-decryption equipment have been included in the preliminary design of the EI links. To preserve traffic-flow security, pseudo-random noise (PSN) data - at the actual data rate - has been placed on the fiber optic links during data-null periods so that the links present a constant degree of apparent traffic to an eavesdropper. Further effort should be made to determine the actual resistance of fiber optics to intrusion to determine actual needs for COMSEC dquipment and procedures.

2.0 SYSTEM REQUIREMENTS

2.1 FI requirements summary.

The purpose of requirements analysis is to provide a framework for designing the intraconnect system. Elements of interest are a definition of the equipment configuration in each TAF operational environment, and a determination of types and quantities of traffic the intraconnect will be required to carry. Analysis of the first element results in a definition of system configuration concepts, and the second in an analysis defining traffic flow within the TAF centers for each concept.

The Flexible Intraconnect concept must satisfy the requirements of TAF systems in the present and near terms as well as those in the future through the year 2000. To account for changes in equipment complements, functional needs, and traffic flow resulting from technological developments expected during this time, five SCCs have been postulated. Each characterizes the architecture of the TAF centers when employing equipment anticipated for that period. By this approach, the long-term requirements of the TAF can be partitioned into scenarios in which system interfaces and traffic-flow determinations can be made. The five SCCs start with the configuration existing presently and then proceed through that postulated for 1990-2000.

A traffic analysis has been done for each SCC. The Flexible Intraconnect will carry traffic between and within shelters at a TAF center. Thus, intershelter and intrashelter traffic is of interest in this analysis. Intercenter traffic is of interest only in its contribution to intracenter traffic flow. It should be recognized that previous traffic analyses for TAF centers have not extended to the inter or intrashelter level; these studies having examined intercenter communications only. Results of these earlier traffic analyses have been used as a starting point for this analysis.

2.2 Operational scenarios.

System Configuration Concepts (SCC). In determining the present needs for information transfer rates and traffic types, a basic system using 407L equipment was established serving as a point of reference for later configurations. Two well established concepts beyond the basic 407L-equipped TAF system were defined by projecting an anticipated evolution of the TAF system based on procurement plans already in progress and on planned procurements of equipment under development.

Two additional concepts were defined that employ equipment not yet developed. These were defined on the basis of information gathered from documents supplied by the Air Force and from studies undertaken by Martin Marietta and show the potential growth of technology to the year 2000.

These five TAF SCCs (Table 2-1), one baseline and four evolutionary configurations, provide the basis for the requirements of a Flexible Intraconnect design. The 407L baseline model was derived from a similar model in Annex A of the TAFIIS Master Plan, Feb 1976, and from TAFIIS Communication Annex E, Feb 1976.

TABLE 2-1. SYSTEM CONFIGURATION CONCEPTS (SCC) DEFINITIONS

SCC-1	Present-1980	
		Classical TAF Configuration
		407L Equipments
SCC-2	1980-1985	
		485L Equipment Improvements
		Adds DCS and WWMCCS Interface
		Introduces DC/SR (TIPI) and PLSS
		JTIDS
SCC-3	1985-1990	
		TRI-TAC Equipment Phased In
SCC-4A	1990-1995	
		Intracenter Computer Bus With Distributed Processing
		Intercenter Computer Links
		Remoted Radars
		Increased Communications Loading on JTIDS and TIPI (EW, ID, GTSC Functions)
SCC-4B	1995-2000	
		Integrated Bus and Circuit Switch
		Distributed/Netted Radars, Radios and Sensors

The System Configuration Concepts are deployed in two zones of activity, the combat and the base zones. Figure 2-1 shows SCC-1 in relation to these zones. SCC-1 uses current inventory 407L equipments and consisting of COMM centers for the air force component headquarters (AFCH), TACC, CRC, two CRPs, four Forward Air Control Posts (FACPs), four (ASRTs), two Direct Air Support Centers (DACSs), two (TACPs), and eight multiwing Tactical Air Bases (TABs). The AFCH, TACC, Airlift Control Center (ALCC), and Tactical Weather Analysis Center (TWAC) are separate, but collocated, elements of the TAF.

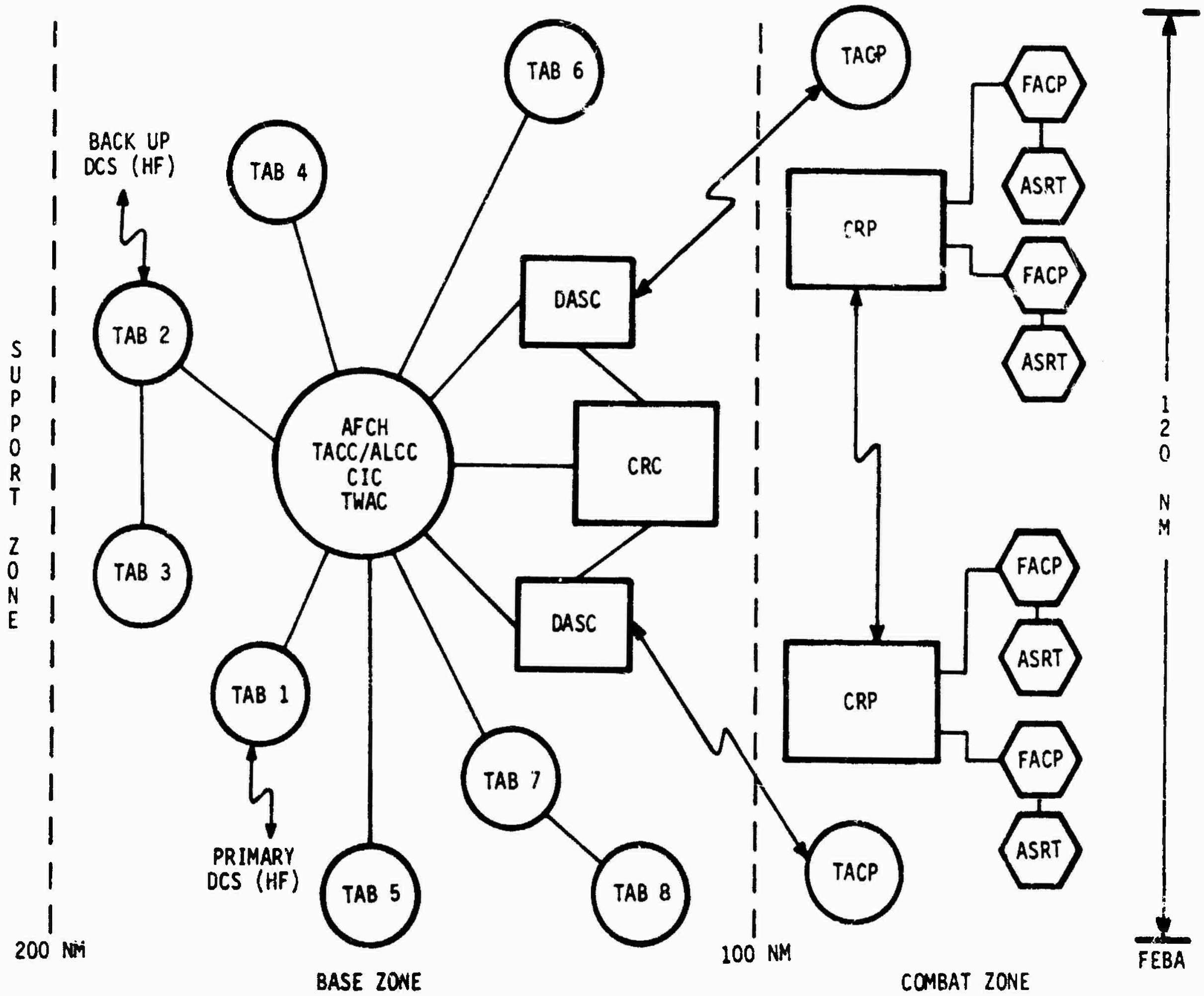


Figure 2-1. SCC-1 baseline model connectivity.

SCC-2 was developed by adding 485L equipment, Tactical Information Processing and Interpretation Display and Control/Storage and Retrieval (TIPI DC/SR), Joint Tactical Information Distribution System (JTIDS), and position Location Strike System (PLSS) to SCC-1. SCC-2 also includes DCS and Worldwide Military Command and Control System (WWMCCS) external interfaces.

SCC-3 introduces the TRI-TAC family of equipment into the Tactical Air Command (TAC). TRI-TAC provides TAC with automated technical control, automated switching, secure transmission of voice and data, digital transmission facilities, and automated system control.

In SCC-4, two concepts, SCC-4A and SCC-4B, are postulated. For SCC-4A, TAC centers retain their identity and functions as defined in earlier SCCs but include both intercenter and intracenter computer exchanges not found in earlier concepts. SCC-4A also accommodates greater communication loads at the centers caused by additional contingents of electronic warfare, identifica-

tion, ground target surveillance, and strike control forces. In addition, the AN/TPS-43 radar is remoted from the control and reporting center and post (CRC/CRP) and includes a decoy. SCC-4B is a concept in which TAC functions do not necessarily reside in the same centers as in the previous SCCs. Functions of circuit switching and channel reassignment as previously performed by the AN/TTC-39 and communications node control element (CNCE) are integrated and concepts of distributed networks of radios, radars, and sensors is introduced. SCC-4B expands the concept of computer-to-computer data communications from that in SCC-4A.

In the following paragraphs, the equipment configurations for each center analyzed are summarized for the five SCCs. The centers are described in more detail in Phase I, Task I Final Report, OR 15,042 Volume II.

2.2.1 Present centers.

2.2.1.1 SCC-1 - baseline concept. SCC-1 a classical deployment of major elements of the Tactical Air Control System (TACS), employ equipment procured under the 407L program (Fig. 2-2).

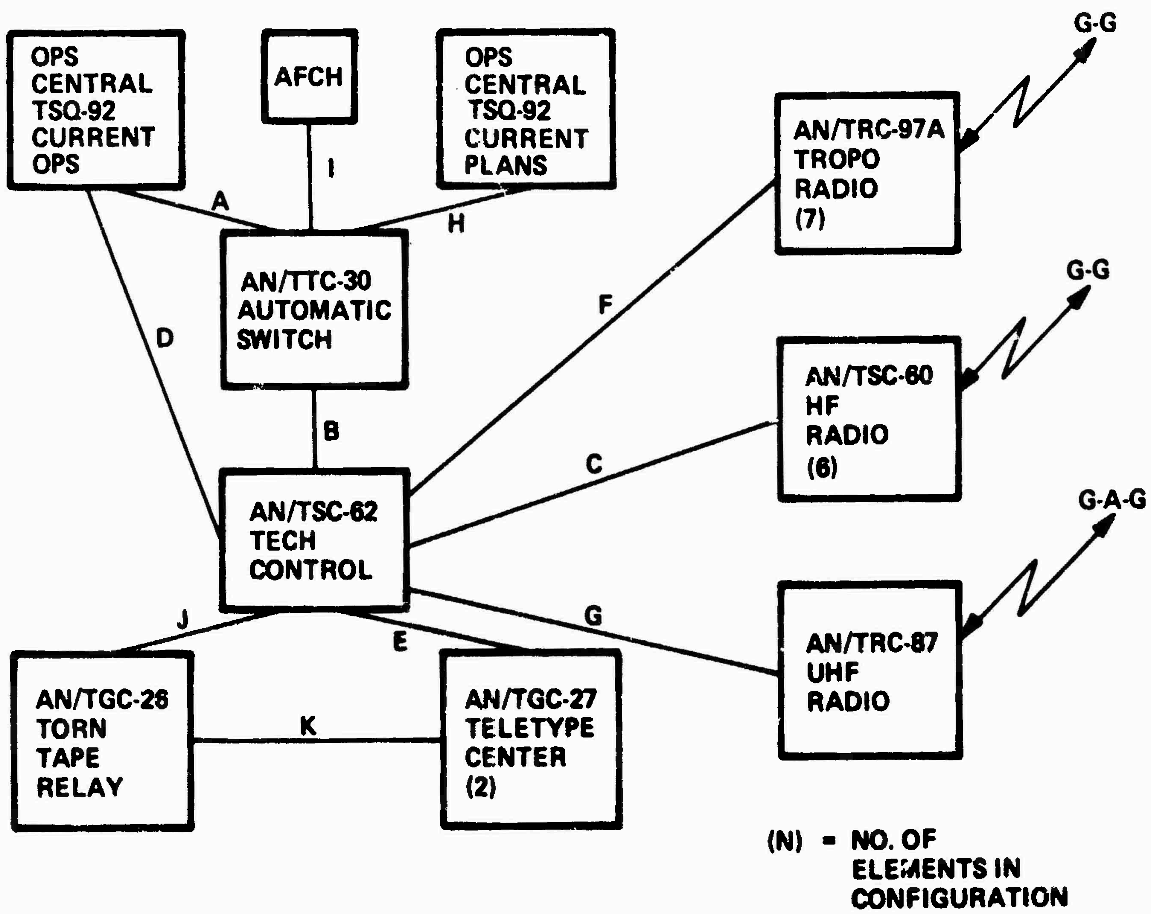


Figure 2-2. Block diagram of AFCH/TACC node for SCC-1.

In SCC-1, voice communication is the prime mode for information flow. Record communication is provided by teletypewriter (TTY) units at the AFCH/TACC with TTY circuits to the TAC units for fragmentary (FRAG) order transmission. Target tracking and identification data are transferred between the CRC and CRPs via TADIL-B data links. Ground-to-air radio nets are provided at each TACS element, airlift, element, and tactical unit operations center (TUOC) as required. Primary long-distance voice and record communications between each of the major Air Force elements are by means of wideband radio systems when required distance and terrain criteria can be met. High-frequency, single-sideband (HF/SSB) radio links are used when terrain or distance prohibit the practical use of wideband radio, or as a limited backup of the wideband links.

Tactical air bases are not treated as a single element for the intraconnect bus plan in this study even though a large number of telephones may be encountered at a multiwing air base. The air base has a group of elements deployed to support the TAF. These elements were reviewed and found to perform generally as isolated and independent operation functions with a limited requirement for high-density communication between them. Two of the elements, the ALCE and TUOC, were selected because they were focal points for the TAB operations and interfaced directly with the TACS. A third system, the Tactical Air Base Weather Station (TABWS), is fully represented in the analysis of the TWAC.

In the baseline system, four ASRTs are deployed, one collocated with each FACP, taking advantage of the FACP long-haul communications to interface with the CRC or a CRP.

The DASCs and TACPs provide organization equipment and personnel through which air support requirements of the ground forces can be identified, processed, and controlled. These elements (especially the TACPs) must move with Army counterparts requiring a high degree of mobility. Battalion-level TACPs are manned with forward air controllers (FACs) to provide air liaison, advice, and integration of close-air support (CAS). The baseline (407L) TAF deployment consists of the following major elements:

a. Air Force Component Headquarters/Tactical Air Control Center (AFCH/TACC);
b. Tactical Weather Analysis Center (TWAC);
c. Airlift Control Center (ALCC);
d. Tactical Unit Operations Center (TUOC);
e. Air Lift Control Element (ALCE);
f. Control and Reporting Center/Control and Reporting Post (CRC/CRP);
g. Forward Area Control Post (FACP);
h. Air Support Radar Team (ASRT); and
i. Direct Air Support Center (DASC).

2.2.1.2 Air Force Component Headquarters/Tactical Air Control Center. AFCH, comprising the command section and various staff groups, is responsible for planning, coordinating, and supervising activities pertaining to performance of the TAF mission. In the baseline configuration, the AFCH is physically located with the TACC and shares a common communications system. Communication traffic loading of the AFCH is included in the TACC traffic analysis since the TACC is the air operations center for the AFCH, (Fig. 2-2).

The TACC is the center of air operations under the command of the AFCC. The TACC plans, directs, coordinates, and controls the deployment of tactical air operations and supervises air control functions to provide centralized control and direction within a TACS. In accordance with the air operations plan provided by the AFCH, the TACC establishes the preplanning associated with tactical missions. This mission preplanning enables the TACC to monitor current air operations and assign allocated resources under its command to incoming requests for various air operations.

The TACC prepares and issues detailed orders for force deployment and monitors the execution of these orders, adjusting to meet established objectives. The TACC is organized into two functional divisions: Current Plans and Current Operations. Under the direction of each division are a number of branches; each responsible for the execution of a TACC function.

The baseline deployment of the AFCH/TACC consists of two AN/TSQ-92 Operations Centrals, an AN/TTC-30 Automatic Switch, an AN/TSC-62 Technical Control Facility, an AN/TGC-26 Form Tape Relay, two AN/TGC-27 Teletypewriter Centers, an AN/TRC-87 UHF Radio, six AN/TRC-60 HF Communications Centrals, seven AN/TRC-97A Troposcatter Radio Sets, and supportive elements for equipments and personnel.

2.2.1.3 Tactical Weather Analysis Center. TWAC is an operational unit of the TACS normally located at the AFCH/TACC to provide weather data processing for the TAF. It provides raw data to and receives tailored weather information from the Air Force Global Weather Central (AFGWC). The TWAC transmits weather information to the TAB local weather centers including data from external sources. Weather information is also transmitted to the CRC, CRP, and DASC.

The TWAC defined for SCC-1 consists of two forecasting modules, one observing module, one radio intercept module, and two maintenance modules (Fig. 2-3).

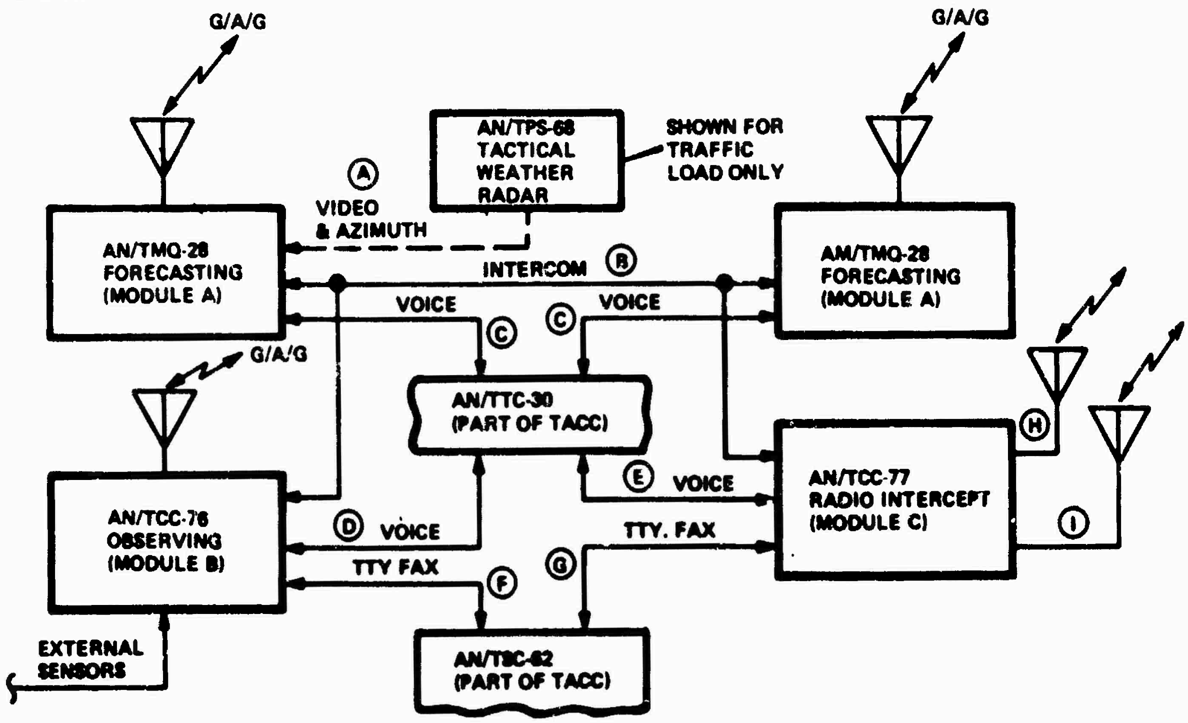


Figure 2-3. SCC-1 tactical weather analysis center.

2.2.1.4 Airlift Control Center. ALCC, the senior airlift element of the TACS, is collated with and subordinate to the TACC, and performs all airlift scheduling and coordinating for the commander (Fig. 2-3).

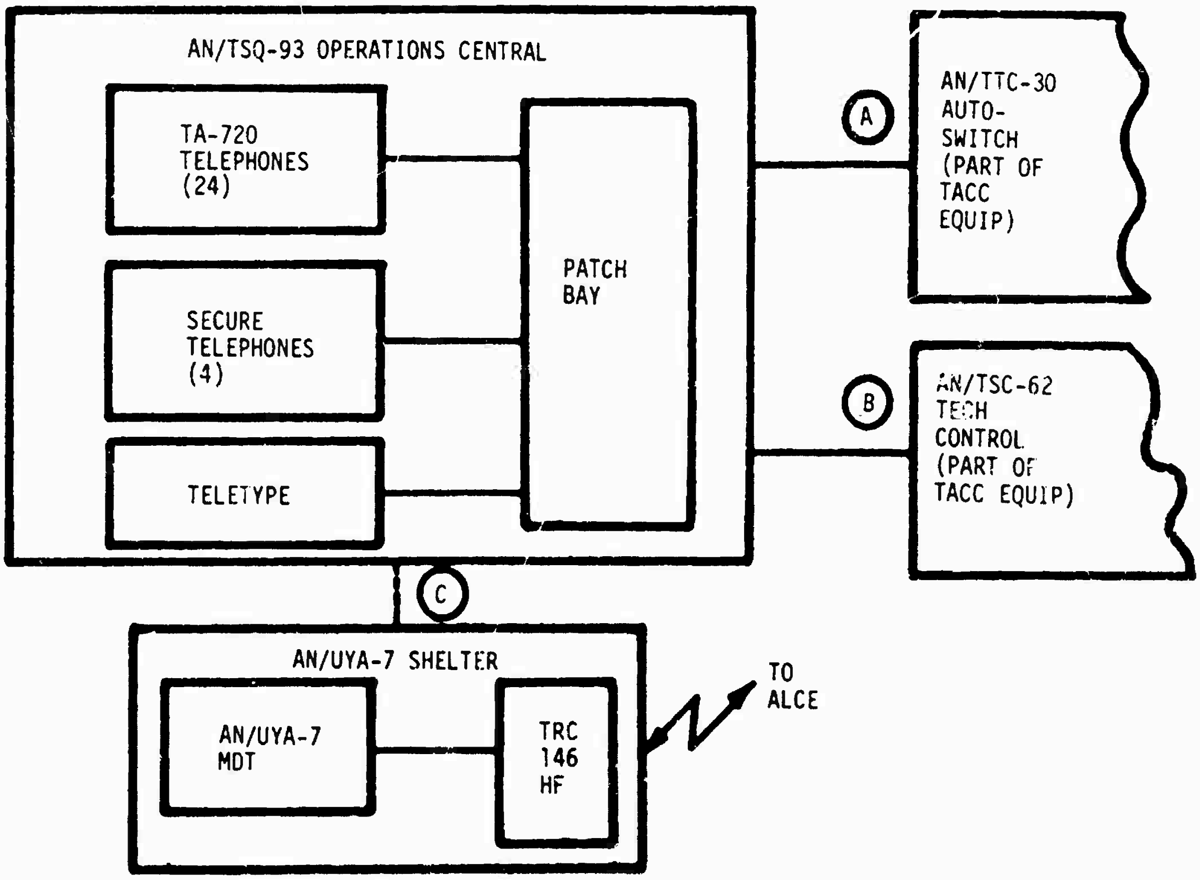


Figure 2-4. Air lift control center.

Deployment of the ALCC depends upon the airlift operation size. For efforts involving less than two airlift squadrons, five to seven Military Airlift Command (MAC) officers will occupy desks in one corner of the TACC. For operations involving more than two airlift squadrons, a separate ALCC shelter (AN/TSQ-93 operations central, medium) is deployed. AN/TSQ-93 contains a manual switchboard (AN/TTC-32) that interfaces with the TACC AN/TTC-30 automatic switch. There are 24 operator positions in the operations central. The AN/UYA-7 and associated HF radios (AN/TRC-146) are located in a separate shelter adjacent to the operations shelter.

2.2.1.5 Tactical Unit Operations Center. TUOC is the operational center of the TAB headquarters where which operations concepts are translated into tactics and mission plans for the application of air power. It provides the link through which operational orders are received, information is displayed, and command directions are disseminated at air bases. At this center, detailed route selections and timeing are decided, air crews are briefed and debriefed, and initial mission reports are prepared and dispatched. The TUOC shares the air base communication equipment, (Fig. 2-5).

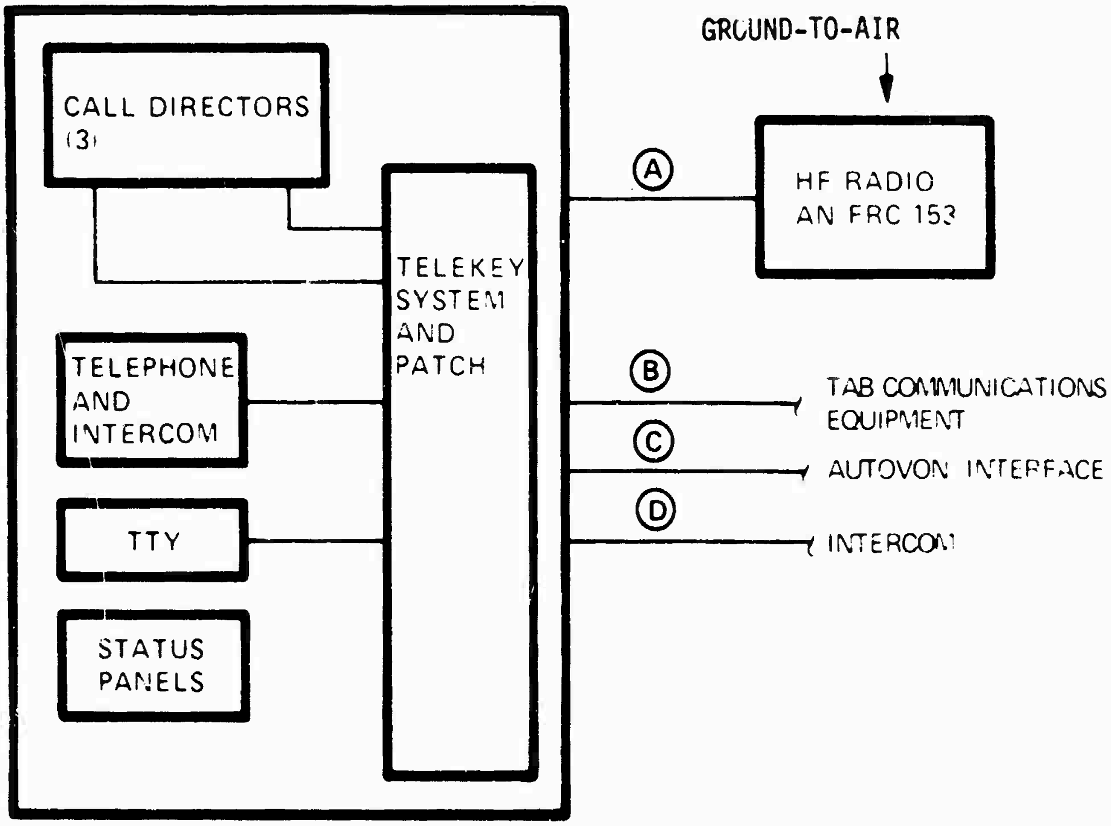


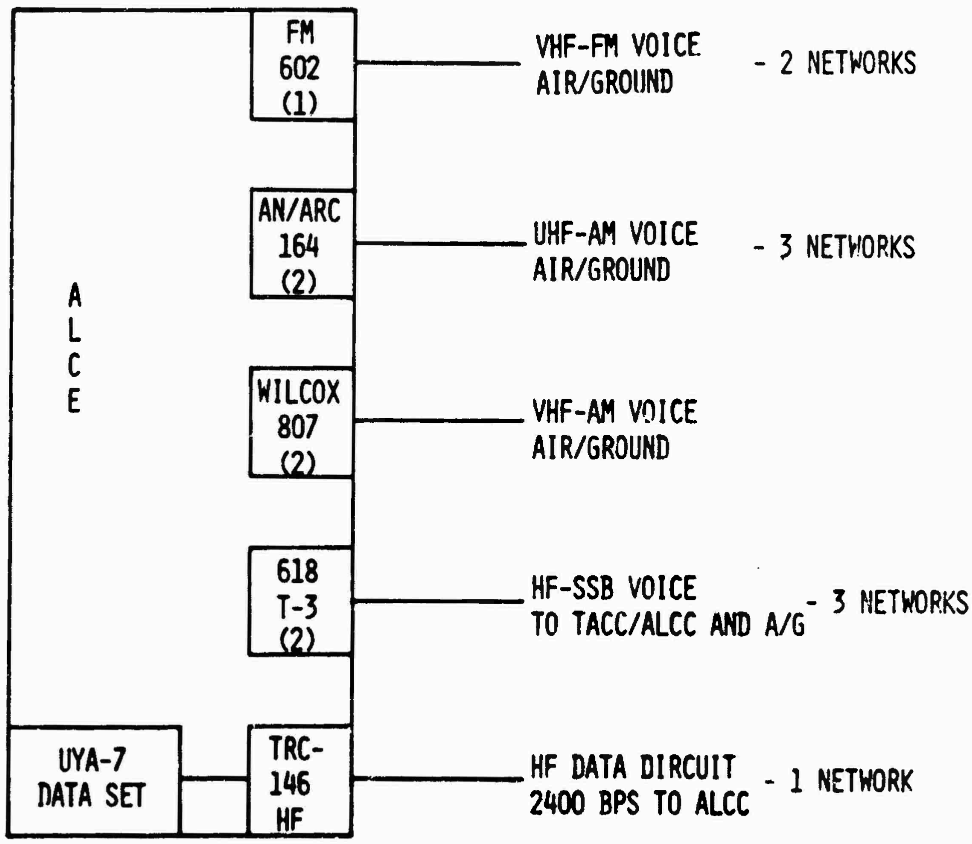
Figure 2-5. SCC-1 TUOC (sharing-TAB communication system).

The baseline TUOC is limited to a manual mode of operation. Through existing TTY, base communication centers, or direct dedicated and common-user voice and UHF/VHF/HF circuits, the TUOC receives daily FRAG orders, intelligence, weather, airfield status, maintenance, and other information regarding the operation mission within its area of responsibility. Since the TUOC is concerned with information to the TACC/ALCC, this facility is required to maintain current status of capabilities of subordinate tactical units served. This information is forwarded to the TUOC via voice and teletype circuits for subsequent transmission to the TACC/ALCC.

2.2.1.6 Airlift Control Element. ALCE is a self-contained module packaged in a single air-transportable expandable shelter and deployed beside the runway of a TAB in the airlift on-load or off-load areas. From this position, ALCE personnel coordinate and control all local airlift operations, including aerial port units and cargo handling teams. ALCE is directly subordinate to the ALCC and is the TACS element through which the AFCC maintains control of assigned airlift forces and ensures their effective employment. ALCE reports loading status to the ALCC via the AN/UYA-7 and the AN/TRC-146 radio. When available, a voice network via the TAB switchboard is provided for backup communications.

Communications for the ALCE are all self contained and organic to the ALCE shelter, (Fig. 2-6). Landline connectivity to the TAB switched-voice network is used for backup communication with the ALCC (when available) and for coordination with other on-base activities. The AN/UYA-7 data sets, associated AN/TRC-146 radios, and various ground-to-air radios are located in the shelter as listed below:

	QUANTITY	USAGE
AN/TRC-146	2	HF-data
618-T-3	2	HF-SSB voice (ground-to-air)
WILCOX 807	2	VHF-AM voice
FM-602	1	VHF-FM voice (ground-to-air)
AN/ARC-164	2	UHF-AM voice (ground-to-air)



NOTE: SCC-2 AND -3 -- NO CHANGES

Figure 2-6. SCC-1, -2, -3 transportable airlift control element.

2.2.1.7 Control and Reporting Center/Posts. The CRC and the CRP are operational elements of the TACS. In the hierarchial structure of the TACS, the CRP reports to the CRC, which reports to the TACC. The CRC is the prime control and surveillance radar facility directly subordinate to the TACC. It is assigned an area of responsibility and it supervises the activities of subordinate radar elements and furnishes appropriate data to the TACC and the DASC.

In SCC-1 the maximum configuration of the CRC is as defined in the deployment described in Figure 2-7. The CRC provides tactical mission control, navigation and air rescue assistance, and threat warning to friendly aircraft. The Air Traffic Regulation Center (ATRC) within the CRC acts as the primary Air Force agency for traffic regulation in the airspace control area. The CRP augments the CRC by extending radar surveillance and airspace control capabilities. If the CRC is not operational, a CRP assumes the primary function of the CRC.

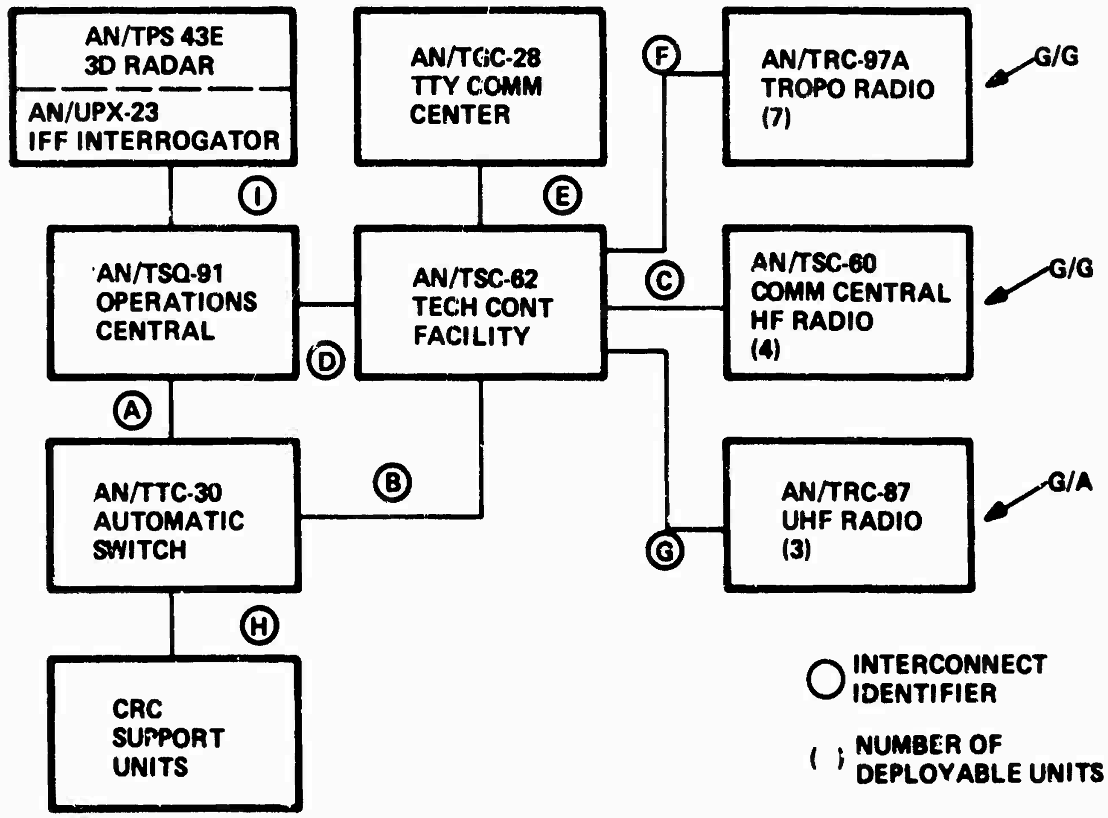


Figure 2-7. SCC-1 Control and Reporting Center (CRP).

The CRC, an operational element directly under the TACC, uses control radars integral to it, and subordinate elements to collect information on all air activities within radar and radio range. This information is then displayed, evaluated, and disseminated throughout the TACS. Within its area of responsibility, the CRC provides defensive and offensive mission control, navigational and air-rescue assistance, threat warning for friendly aircraft, and the means for air traffic regulation and identification.

The AN/TSQ-91 operation centers used at a CRC/CRP are developed from modular transportable packages, which when deployed, form an operations room. The maximum configuration for a CRC/CRP will use three console modules (CM), one data processing module (DPM), one ancillary equipment module (AEM), three group display modules (GDMs), and two air conditioning modules (ACMs). The CM contains four multipurpose display consoles, four associated technician stations, and sufficient electronics to integrate with radar, communications, and data display equipment.

The AN/TRC-97A is the tropo radio set used to interconnect nodes providing the ground-to-ground transmission network.

The AN/TSC-60 is an HF communications central.

The AN/TRC-87 is the UHF radio central used for ground-to-air communication.

2.2.1.8 Forward Area Control Post. The FACP is a mobile element that operates close to the forward edge of the battle area (FEBA). Subordinte to the CRC or CRP, it is used to extend radar coverage. The baseline system employs four FACPs, each with an ASRT collocated. The ASRT shares the FACP communications and appears at he same node in the traffic analysis, Fig. (2-8).

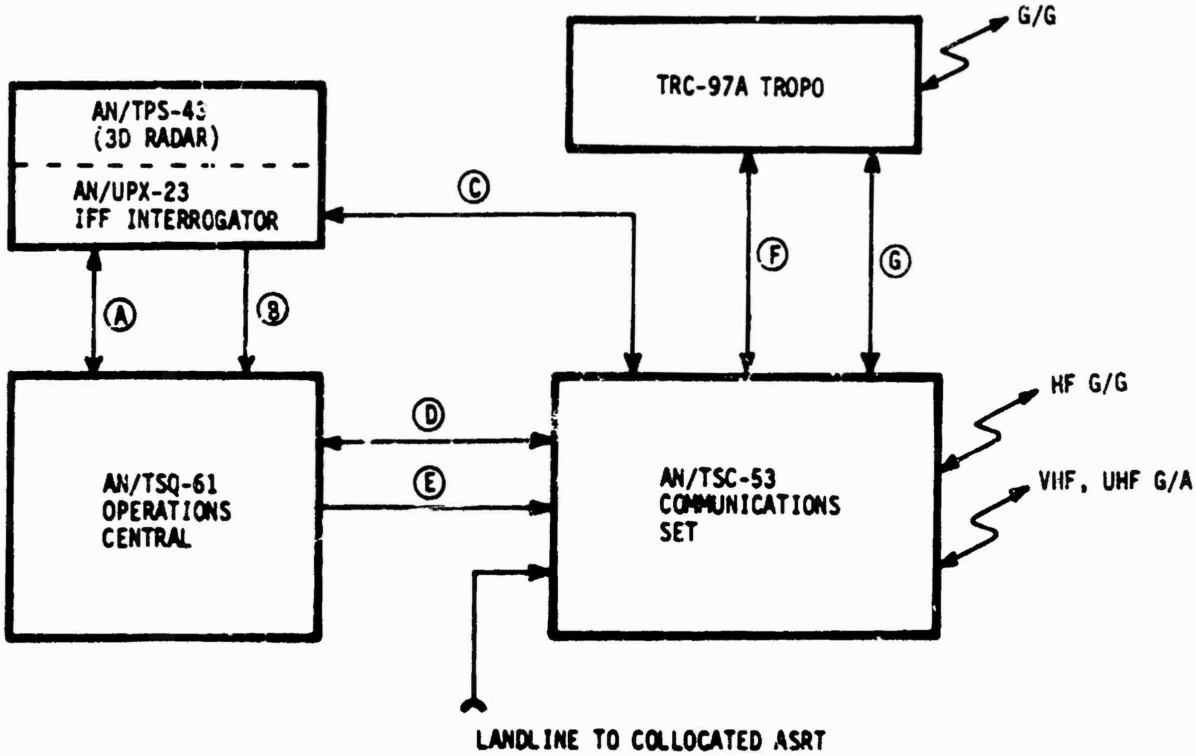


Figure 2-8. SCC-1 and SCC-2 Forward Air Control Post (FACP).

In this study, the surveillance and control radar used is the AN/TPS-43E (three-dimensional, S-band tactical radar). It is also assumed that the AN/TSQ-61 Operations Central is modified by installing the AN/TPS-43 radar interface equipment and the associated displays and IFF (identification-friend or foe) systems.

2.2.1.9 Air Support Radar Team. ASRT is a mobile system equipped with a precision radar to provide all-weather guidance for tactical strike aircraft against ground targets. A television (TV) camera is mounted on and aligned with the radar antenna for boresignting the system and visual tracking when feasible. The system provides positioning capability for reconnaissance and airlift aircraft over predetermined coordinates via UHF radio using voice and tones for guidance.

The baseline ASRT is deployed in the forward combat area in proximity to the FACP. The ASRT also shares the long-haul communications radio of the FACP. ASRT is a ground-radar instrument bombing and guidance system with precision terminal guidance capability for providing range, altitude, and azimuth instructions to tactical aircraft. The ASRT can control close air support aircraft under all conditions of weather and visibility.

Basic components of the TPB-1B/C system (Fig. 2-9) are the radar, operator console, communications, TACAN, and computer. These components are:

a. Precision I-band radar (8.0 to 10.0 GHz) is capable of automatically acquiring and tracking beacon-equipped aircraft; the TPB-1C can also skin track.
b. Operator's console has panel switches for input of target coordinates, ordinance type, meterological data, and acquisition sector. The panels also display real-time aircraft position data and guidance parameters. A plot board displays current aircraft position relative to the radar and/or target.
c. Two UHF radios (AN/ARC-164) are used for voice communications, and voice and tone guidance to the aircraft.

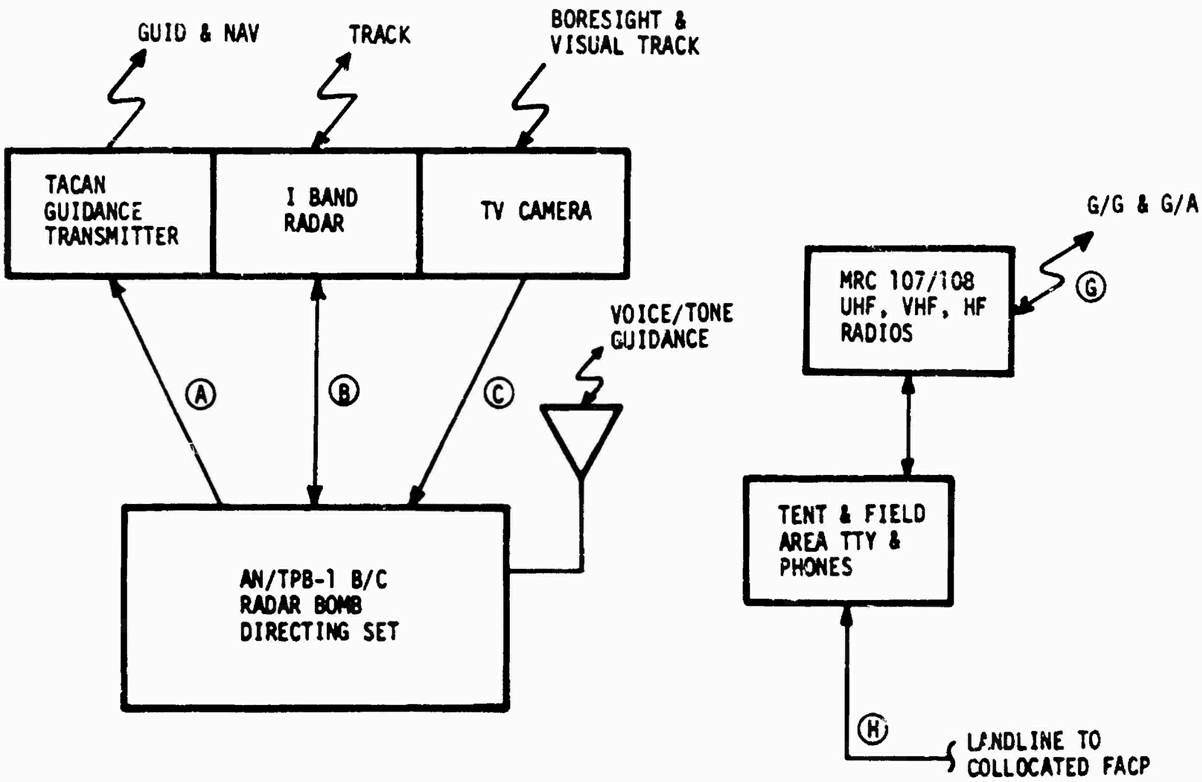


Figure 2-9. SCC-1 Air Support Radar Team (ASRT).

ASRT is normally deployed with the AN/MRC-107/108 Mobile Communications Central to provide communications for independent employment or backup. When operating independently, the AN/MRC-107/108 communications interface is with the CRC/CRP/FACP to relay air tasking orders from the TACC Current Plans Division and to provide track handoff exchanges. Aircraft positioning information is transmitted to the aircraft under ASRT control via UHF (two each AN/ARC-164) radios, or VHF/FM from the AN/MRC-107. the ASRT is only capable of troposcatter radio communication when collocated with another facility having this capability, such as the FACP in the SCC-1 deployment.

2.2.10 Direct Air Support Center. DASC is a mobile, air transportable element designed to operate with the appropriate Army Tactical Operations Center (TOC). It is normally collocated with an Army corps or division conducting independent operations, while receiving and coordinating Army requests for immediate close air support, tactical air reconnaissance, and assault airlift missions.

The DASC maintains direct contact with TACPs, aircraft in its sector, and Army elements. Requests for immediate tactical air support are transmitted over the Air Force air-request net, which extends from the TACCs to the DACS. The DASC is subordinate to the TACC.

The baseline configuration of the DASC is assumed to be the maximum configuration as shown in Figure 2-10. The focal point of the DASC is the Operations Central AN/TSQ-93, which consists of three operation modules and one communications module. The communications module provides technical control capabilities and voice TTY communications for the DASC.

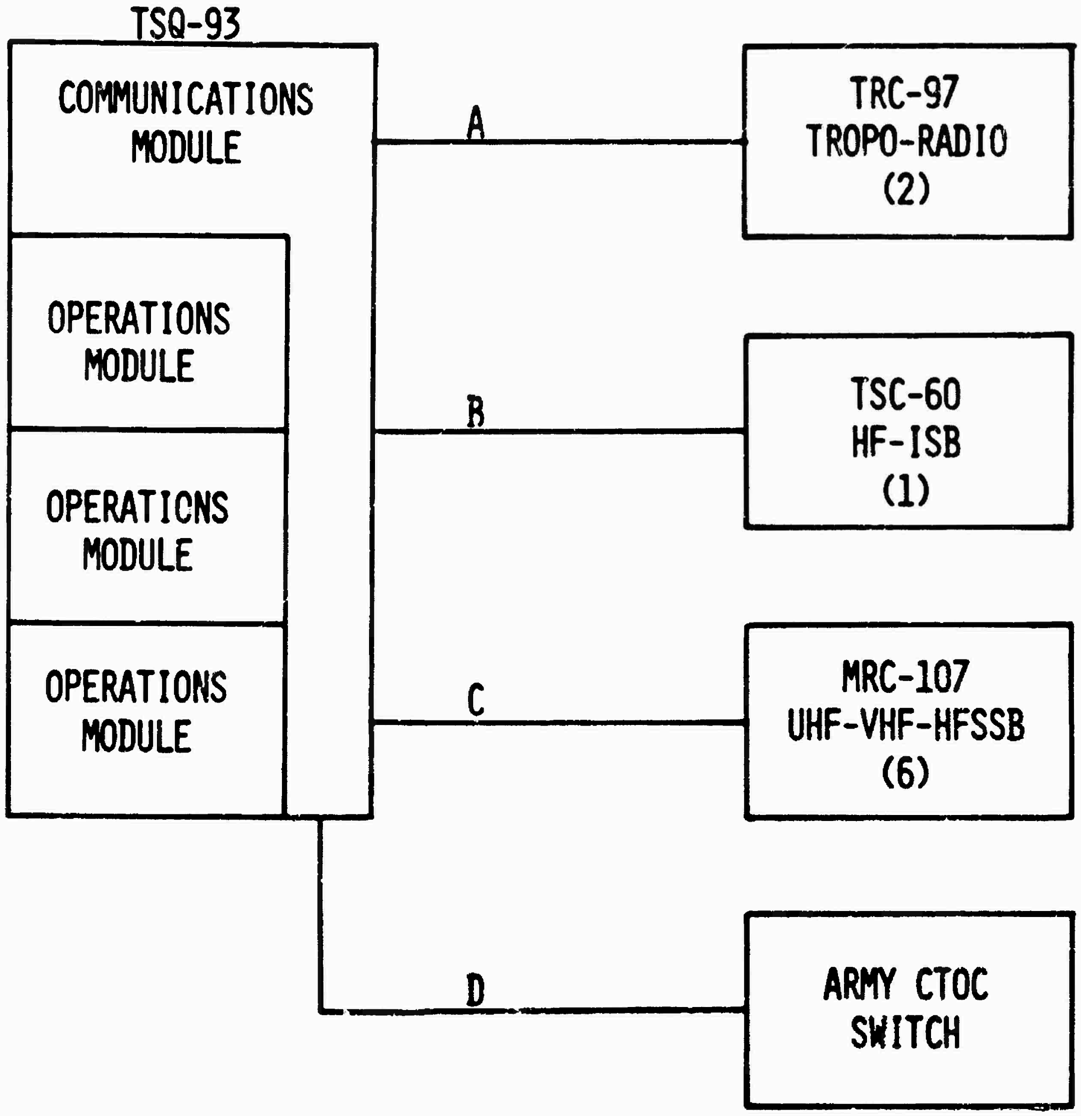


Figure 2-10. SCC-1 and -2 Direct Air Support Center (DASC).

2.2.2 Future modifications.

2.2.2.1 SCC-2 TAF automation concept. The second system configuration concept, SCC-2 (Fig. 2-11) defines the changes to the baseline TAF system brought about by automation in the 485L program, the 428A Tactical Information Processing and Interpretation (TIPI) Display Control/Storage and Retrieval (DC/SR), the Joint Tactical Information Distribution System (JTIDS), and the Precision Location Strike system (PLSS). The communications impact from these systems on the present TAC architecture is assessed.

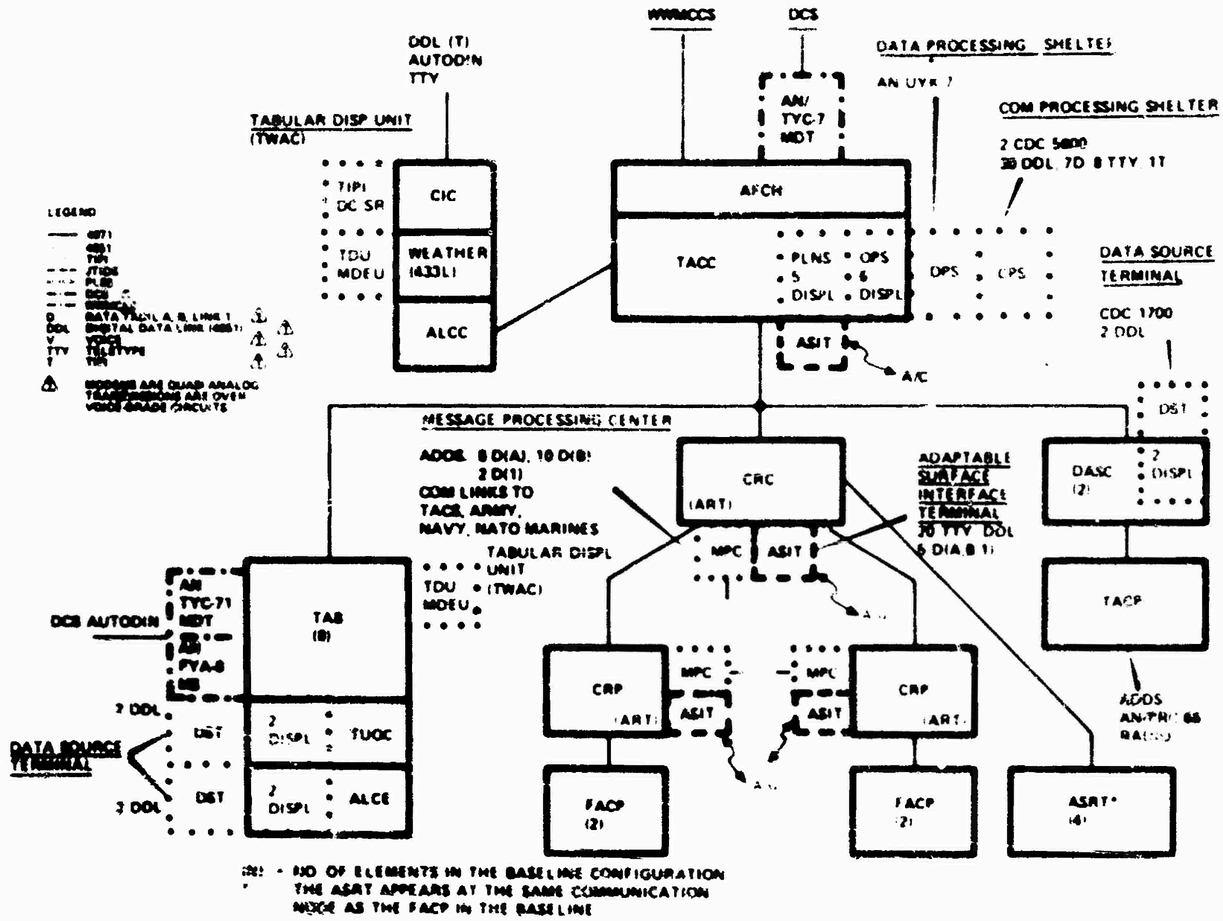


Figure 2-11. SCC-2.

2.2.2.1.1 485L TACS automation. The 485L program upgrades the present TACS system by automating manual information processing and display capabilities in the TACC AN/TSQ-92 Operation Central, DASC AN/TSQ-93 Operations Central, existing ALCE and TUOC facilities, and CRC/CRP AN/TSQ-91 Operations Central. The capability is provided to digitally exchange air surveillance and other information with other TACS centers as well as with other services, i.e., the Army, Navy, Marines, and NATO. The 485L program also automates the Aerospace Management System (AMS) and the Automatic Radar Tracking (ART) function, and makes various other improvements not affecting the system interface.

2.2.2.1.2 Joint Tactical Information Distribution System. JTIDS is a high-capacity, time-division, multiple-access communication and information distribution system. It is being developed to facilitate secure, flexible, and jam-proof information transfer in real time among the dispersed and mobile units. The most significant and unique characteristic of JTIDS is that all participants exchange information over a single communication link. This system constitutes an information pool that is continuously updated by each participant. It will be implemented initially in large aircraft of the AWACS, and will be extended to fighter aircraft and other tactical ship and shore elements.

JTIDS interfaces with elements of TAC by the Adaptable Surface Interface Terminal (ASIT), which can be located at any TAF center. ASITs, which have been planned for at least the TACC and CRC/CRP, are to interface the JTIDS network with the TADIL-A, TADIL-B, link 1, and DDL networks of the TAF, allowing interchange with TAF data processors.

2.2.2.1.3 TIPI DC/SR. TIPI interfaces the DC/SR with the TACC (485L) via the DDL and TTY. The comm processor shelter in the 485L TACC houses the TIPI interface equipment. Teletype circuits operate at 75-band, with FSK modulation at 1317.5/1232.5Hz. The DDL operates at 150, 300, 600, 1200 and 2400 b/s. In TIPI, the DC/SR comm shelter houses the modems, and crypto and line controller equipment, which interface with the comm processor. TIPI supports the following functions:

a. Fusion;
b. TERPE;
c. Image Interpretation (II);
d. Manual Radar Reconnaissance Exploitation System (MARRES); and
e. Photo Processing and Interpretation Facility (PPIF).

2.2.2.1.4 Precision Location Strike Subsystem (PLSS). PLSS uses more than one aircraft at a time to locate an emitting targe, and provides information to attack aircraft for homeing on targets from computations supplied by a ground computer. A Ground Control Center (GCC) is required to collect sensor data from the aircraft and provide computation and fusion support. The A/G link is JTIDS. The GCC may be located at a TAB or a forward area. There is a data link to the TACC and CIC from the GCC. The data are sent to the CRC/TACC for response by mission aircraft ground alert and airborne strike forces. The ground computer station and TACC coordinate drones instead of manned aircraft for certain applications.

2.2.2.2 SCC-3, TRI-TAC equipment. SCC-3 introduces the TRI-TAC family of equipment into TAC. TRI-TAC provides the transition from the predominately analog communication system in SCC-1 and SCC-2 to the all-digital system existing when the phase-in of TRI-TAC equipment is complete. TRI-TAC provides TAC with automated technical control, automatic switching, secure transmission of voice and data, digital transmission facilities, and automated system control, (Fig. 2-12). The TRI-TAC family comprises the following equipment:

a. Communication Nodal Control Element. The CNCE provides technical control functions for the transmission system and the switches assigned to it.
b. Communication System Control Element (CSCE). Control of up to 16 CNCEs is provided by a CSCE.
c. Circuit switch and message switch (AN/TTC-39). The AN/TTC-39 circuit switch and message switch provide switching, call processing, and traffic control functions for digital telephone and message traffic.
d. Unit-Level Switchboard (ULS). The ULS provides circuit switching and call processing of digital traffic at a lower level in the hierarchy than the AN/TTC-39 and has less capacity.
e. USAF Short-Range Wideband Radio (SRWBR). The SRWBR provides a wideband transmission facility for both analog and digital transmission groups. It interconnects the CNCE with long-range transmission facilities such as tropo and line-of-sight (LOS) nodal radios.

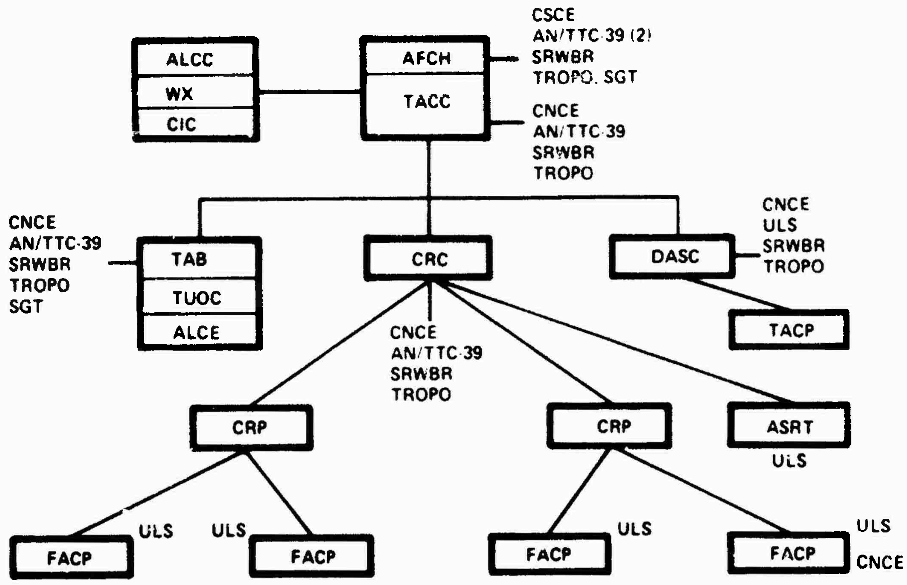


Figure 2-12. SCC-3 TRI-TAC.

When phase-in of TRI-TAC equipment is complete, the TAF centers will have undergone major changes. CNCEs replace the AN/TSC-62 technical control, AN/TTC-39 switches replace the AN/TTC-30, and the AN/TRC-170 digital tropo replaces the An/TRC-97 analog tropo. A CSCE is added at the AFCH, and an SWRBR is added at each CNCE to carry transmission groups from the CNCEs to top-of-the-hill radio sites. Satellite Ground Terminals (SGT) are added at the AFCH and TAB with TRI-TAC multiplexers, modems, and COMSEC equipment. the SGT may be used for DCS entry, which JTIDS serves as the primary surveillance net communication medium. Unit-level switches are deployed at ASRTs and FACPs, and, when they are collocated, ASRTs share CNCE equipment with FACPs.

2.2.2.3 SCC-4 technology trends and potential TAFIIS architecture. This part of the analysis examines the impact of technology trends and potential TAFIIS architecture, and addresses the implications of distributed data bases, dynamic resource allocation, graceful system degradation, and load sharing. The effects of the intraconnect bus in decentralizing certain functions such as the CRC and mission planning are also addressed.

Two SCCs are postulated. First is the SCC-4A, in which the TAC centers retain their identity and function as defined in earlier SCCs, with the SCC-4A having both intercenter and intracenter computer exchanges not found in earlier concepts, and accommodating greater communication loads at the centers caused by additional contingents of electronic warfare (EW), identification (ID), and ground target surveillance and strike control (GTSSC) forces. In addition, the AN/TPS-43 radar is remoted from the CRC/CRP and its deployment includes a decoy. The second is the SCC-4B, a concept wherein TAC functions do not necessarily reside in the same centers as before. The functions of circuit swiching and channel reassignment of the AN/TTC-39 and CNCE re integrated and the concepts of distributed networks of radios, radars, and sensors is introduced. SCC-4B also retains the concept of computer-to-computer data communication from SCC-4A.

2.2.2.3.1 SCC-4A integrated switching and distributed networks of radars, radios, and sensors. The SCC-4A concept is introduced to assess the impact of systems that are relatively new to TAC but which do not significantly change the architecture of the centers supporting them. This allows a more independent assessment of the effects of these systems on the intraconnect bus concept. Most systems considered here have their beginnings in SCC-3, and some as early as SCC-2. However, their impact on the traffic load is minimal until the systems are fully developed and operational in SCC-4A. SCC-4A features are as follows:

- Intracenter computer busses;
- Intercenter computer links;
- EW,ID,AS and AC/GTSSC additions to TAC; and
- Remoted AN/TPS-43 radars at the CRC/CRP.

The increase in communication and data handling loads placed on the TAC in SCC-4A is caused by the introduction of, or improvements to, many of the new functions listed in Appendix E. The most significant are categorized here by function. They are included to characterize the concept and provide as much insight as possible into the nature of a future TAF that is still mostly conceptual.

Figure 2-13 shows the features of SCC-4A in the TAC hierarchy.

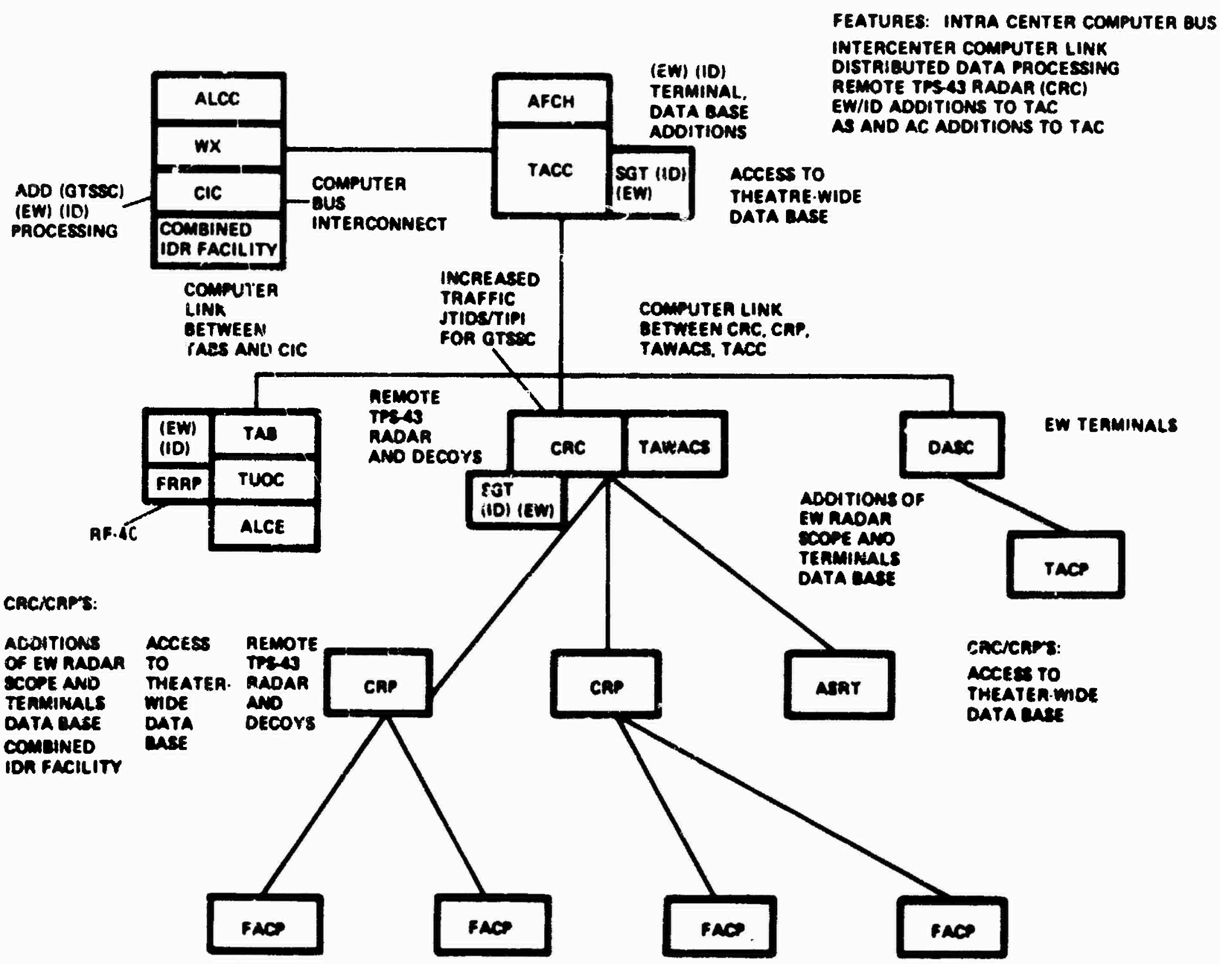


Figure 2-13. SCC-4A.

2.2.2.3.1.1 Electronic Warfare (EW). The addition of antiradiation missile (ARM) decoys, and remotely piloted vehicles (RPVs) with jammers, and the development of electronic intelligence (ELINT) satellites and other systems require the addition of a complete EW management capability to TAC. Additions to personnel facilities and equipment capabilities will be required as well as a sophisticated communication system. An EW controller will be required at CRC/CRP with a radar scope and access to a special EW data base. The EW management function will be distributed for survivability. What has been performed by TIPI in the CIC will now be distributed to consoles at the CRC, TACC, AFCH, DASC, and TAB. JTIDS will be used for much of the EW communications. Therefore, the impact of the EW team on the TAC is to add terminals (consoles) to TABs and the CRC/CRP, add data links to control decoys and netted radars, and provide additional links from ELINT satellites and aircraft via JTIDS.

2.2.2.3.1.2 Ground Target Surveillance and Strike Control (GTSSC). The impact of GTSSC systems is to add a greater load on JTIDS* and TIPI data links and to require increased speed and quantity of data processing. Continuous target tracking is a goal of the target acquisition function that, among other things, requires target information handoff through several zones of operaion. Referred to as "timely all-source data correlation," this requires improved speed and quantity of data handling.

Transmissions from improved Side-Looking Radar (SLR) and the near realtime transmission of data from reconnaissance functions such as tactical electronic reconnaissance/processing and evaluation functions (TEREC/TERPE), place increased loads on the tactical air intelligence system (TAIS) at ACIC. The inclusion of PLSS for stationary target location/strike, and the Multilateration Radar Surveillance strike subsystem (MRS3) for mobile targets adds to the load further. The load of JTIDS and TIPI facilities for GTSSC functions of target acquisition, fuzing, planning, commitment, control, and strike is generally within the capabilities of these systems, but it increases significantly as the systems are used more widely in the TAC.

2.2.2.3.1.3 Identification. The impact of ID functions of SCC-4 follows the same pattern as EW and GTSSC, i.e., the systems tax TIPI resources, but function within the presently defined TIPI framework. TISEO, LATAR, TRISAT, and DMR systems are ID techniques that may be correlated to provide positive aircraft ID. A requirement exists for a combined identification resource (IDR) facility that can receive inputs from many sensors, each impinging on the aircraft in question, and provide ID based on the highest probability resulting from their combination. Several combined IDR facilities will be deployed, some in forward areas, probably CRC/CRP or FACP, and at least one in the ACIC.

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*The present generation of JTIDS is not expected to handle the increased requirements imposed by future systems. It is assumed that JTIDS will either evolve to meet these requirements or be replaced by a similar system in the future.

2.2.2.3.1.4 Air Surveillance (AS) and Airspace Control (AC). Several improvements have been planned for AS and AC (Appendix E), but only one is significant for SCC-4A: The addition of Tadil-B forward tell from the FACP to CRC. This is part of an automation change to the manual FACP which also adds computer aids, improved display, and the TPS-43E 3D radar instead of the 2D radar, TPS-44. The TADIL-B link will be replaced by JTIDS in SCC-4B and the FACP will become a part of the fragmented, decentralized CRC concept. The FACP radar may be remoted via fiber optic cable or microwave for ARM protection.

2.2.2.3.1.5 Communications. Communication improvements for SCC-4A include the increased use of JTIDS, increased number of data links for TIPI functions, E-3A enhancements quick-strike reconnaissance (QSR), MRTT cluster adaptations, and remoting TPS-43 radars from the CRC/CRP and FACP.

QSR is a system that exploits real-time imagery from an RF-4C. In target development, selected imagery or target information is transmitted by data link to a recon reporting post (RRP) at the TAB or TACC where it is analyzed, condensed, and relayed to the TEREC and MARRES segments of TIPI at the ACIC. In the strike control and reconnaissance role, the QSR RF-4D will directly support strike activities using coordinate transfer, laser designators, and target markers. The RRP will consist of a compass sight signal/receiving van and a TIPI auxilliary shelter that accommodates infrared (IR) and forward-looking IR (FLIR) imagery transmitted over the digital data links.

To accommodate increased digital traffic, clusters of modular record traffic terminals (MRTT) may be added to the present centers as required, and function as message centers. The MRTTs may use a modified version of the AN/UYA-7 or its equivalent.

The AN/TPS-43E radar at the CRC and future FACPs may be remoted from the center over distances of several kilometers by fiber optics or microwave. In either case multiplexed Digitally Coded Radar (DCR) transmissions are assumed. Studies of DCR concepts and microwave vs fiber optics are presently being performed by the Air Force. The remoting of radars and the deployment of decoys are needed to counteract the effects of antiradiation missiles. The deployment of one or more decoys at a radar site will add additional circuits from the control site to the decoys.

2.2.2.3.2 SCC-4B distributed and netted radars, radios, and sensors; integrated bus, circuit switch, and channel reassignment. The SCC-4B (Fig. 2-14) introduces the concepts of radios, radars, and sensors deployed in distributed networks, and provides the integration of the switching functions of the circuit switch and CRF of the technical control facility with functions of the intraconnect bus. The systems introduced in SCC-4A apply to SCC-4B except as modified in these areas.

Integrated bus, switch, and channel reassignment. In SCC-4B, the intraconnect bus provides the switching functions that were previously performed in the circuit switch and technical control facility. When the intraconnect bus concept was introduced, these switching functions were duplicated in the bus and became redundant.

With the advent of newly designed equipment in SCC-4B, it is feasible to introduce this concept and hence eliminate such redundancy at considerable savings in equipment. The functions duplicated are the circuit switch matrix, the store and forward switching matrix in the switch, and the CRF in the CNCE. The technical control functions associated with the switch and CNCE are retained separate from the bus. Such functions include automatic digital and analog testing, traffic load control, call handling, encryption, and all such functions related to the traffic control of the switched network and transmission system.

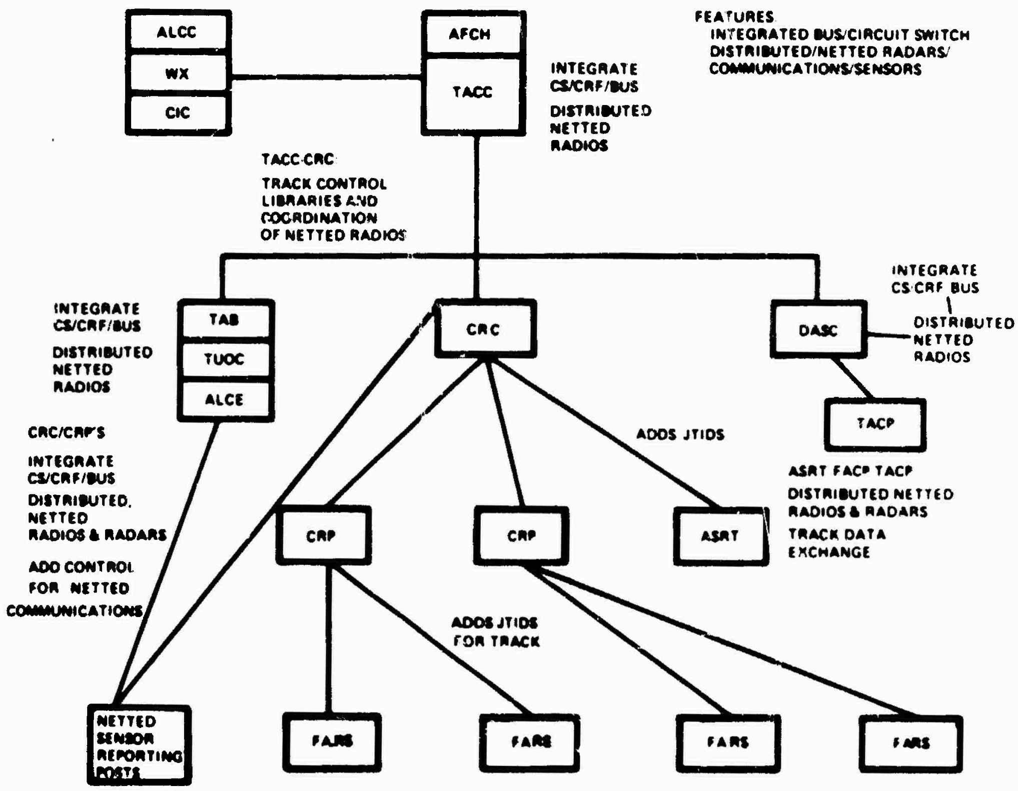


Figure 2-14. SCC-4B.

Radars, radios, and sensors in distributed networks. In future systems, the trends will be toward replacing long-range radars and radios with low-powered, short-range systems deployed in networks having overlapping coverage and redundant transmission paths. This is to protect against ARM attacks and provide self-healing characteristics when transmitters are lost. The tendency toward netted sensors to provide real-time distribution of sensor data for fusion purposes and dissemination to commanders and strike forces. The networks of radars and radios require control links to coordinate transmissions. The transmitters may emit on pseudorandom schedules designed to confuse ARMs. Reporting links are required from the radars, radios, and sensors to their appropriate centers for coordination. JTIDS will provide the network necessary for real-time disemination of sensor data, strike control, and, with modifications, may be adequate for radar track data. It is not however, expected to handle node-to-node communication trunk groups. Other radios, radars, and control data links will therefore be required. Control of node-to-node radios can be sent in data orderwire overhead channels of trunk groups.

In the concept of distributed, netted radars, the CRC/CRP functions become decentralized into a network of FACP-size, dispersed along the FEBA. In some cases where a CRC can be located far enough from the FEBA, a longer range radar such as the AN/TPS-43 may be deployed to coordinate track and other data from the network of radars. In addition, radar transmitters may be detached from receivers to separate ID functions from surveillance. EW air controllers may be located remotely from surveillance and require a separate radar scope and data base. These changes place greater loads on the interconnecting data links in the network.

Radars may be located in space to provide the area coverage of a CRC or to aid in the ID function. The purpose of the ID function is to designate regions in which ID by sensor is to be performed, thus providing a coarse search for narrow-beam type sensor interrogation or to provide ID at great distances.

2.3 Interfaces.

TAF interfaces with other military systems at TAF centers. TAF centers communicate with each other, and each center has interfaces between shelters. Intersystem and intercenter interfaces are of interest because the traffic they carry adds to the overall load carried at a center. Intracenter interfaces are of interest not only because of the traffic they carry, but from an electrical standpoint as well. It is the intracenter interfaces with which the FI must be compatible at the equipment level. Therefore, the external and intracenter interfaces have been analyzed from a traffic point of view and the intracenter interfaces have been defined at the equipment level.

2.3.1 External and intracenter interfaces. External interfaces of interest are with the defense communication system (DCS) and the World Wide Military Command and Control System. Intercenter interfaces are in voice, TADIL-A, TADIL-B, Teletype, Digital Data Links, and facsimile. These interfaces are detailed in Phase I, Task I, Final Report, OR 15,042.

2.3.1.1 Defense Communication System (DCS). DCS provides communication between the theater of operations and other parts of the world. DCS circuits terminate at one or more points designated as DCS entry and alternate DCS entry in the tactical theater. The DCS consists of AUTOVON, AUTODIN, and other specialized transmission means. The logistics and personnel systems of the TACS use AUTODIN-compatible communication. WWMCCS uses voice, TTY, and AUTODIN.

DCS entry into the TAF is at the AFCH. The DCS AUTODIN interface at the AFCH is via the AN/TYC-7 MDT, and the alternate DCS entry is at a TAB. The AN/FYA-7 or AN/TYC-8 data source terminal is the AUTODIN interface at a TAB.

2.3.1.2 Worldwide Military Command and Control System (WWMCCS). WWMCCS automated data processing system is managed by the Joint Chiefs of Staff (JCS) and includes 35 medium-to-large computer systems and their associated remote terminals. These configurations are geographically distributed over 18 time zones from Taiwan to Germany. Their purpose is to support planning for the employment and command and control of all armed forces by the President, Secretary of Defense, JCS, and major commanders in the field.

Interface between WWMCCS and TACS is at the AFCH. The operations control of the AFCH/TACC is where national tasking data are received and transformed into executable plans and orders, missions are controlled, and subsequent results are fed back to the national level. Presently the WWMCCS/TAC interface accommodates data exchange by an interim system. A remote terminal system (RTS) at the AFCH/TACC accesses the WWMCCS computer via a data link. The RTS is also accessed by AN/UYA-7 MDTs via a flexible data terminal (FDT), which is the ALCC-to-ALCE link.

The 485L will replace the RFS and FDT with TDU/MDEUs connected to the DST at the ALCE and the DP&D module at the TACC (assuming the ALCC does not have a DST of its own).

2.3.2 Intracenter interfaces. Intracenter interfaces are those between equipments in a shelter and between shelters within a TAF center, which will be used by the FI. In present TAF configurations, such interfaces are interconnected by multiwire cabling or COAX which will be replaced by the FI system.

Intracenter interfaces have been separated into two categories to facilitate the analysis: Automatic Data Processing (ADP), and Communication (COMM) interfaces.

2.3.2.1 Communication equipment interfaces. The objective of this part of the analysis is to identify all the interfaces between TAF communication devices and the Flexible Intraconnect (FI) that are essential to the operation of TAF equipment centers, and to define their characteristics are useful in the design of the FI.

All communication devices which are in the present inventory, as well as those under development, will require adapters to interface the FI. Those in future devices may be designed to interface without adapters.

The initial step in identifying the communication interfaces is to provide a list of all major equipment assemblages, and identify the communication devices comprising each. It is convenient to identify equipment assemblages by TAF centers, as each center is defined by system configuration concepts (SCC). Equipment assemblage complements are identified for each SCC from the present to 2000. This provides a convenient evolutionaly summary of all equipment used in the TAF over the period covered by the FI study. In general, devices within each shelter are not herein identified. Refer to Volume II, Task I Final Report for identification of devics within each shelter.

The following tables, Table 2.2 thru Table 2.6, list equipment assemblage complements for the TACC, CRC/CRP, TAB/TUOC/ALCE, DASC, and FACP/ASRT.

The term "integrated" in the tables refers to the integration of call processing switching, and technical control functions of the automatic circuit switch and nodal control element within the FI. "Netted" refers to the concept of replacing long-range radar and radios with short and medium-range networks of radars and radios. These concepts are described for SCC-4B in Volume II of the Task I Final Report.

The model identifier after each shelter number is an arbitrary designation which denotes a functional change which has been based on a change defined in the Task I Final Report.

2.3.2.2 Critical communication interfaces. The devices within those shelters listed in Tables 2-2 thru 2-6 have been identified and listed in Phase I, Task II Final Report. The result is a list of all the important communication interfaces for all centers and all SCCs. The interfaces which are known to be critical because of their common usage or signal characteristics are identified.

TABLE 2-2. TAC EQUIPMENT/SHELTER BY CENTER TACC

Equipment/Shelter	SCC-1	SCC-2	SCC-3	SCC-4A	SCC-4B
Current Ops	AN/TSQ-92(1)	AN/TSQ-92(A1)	AN/TSQ-92(B1)	AN/TSQ-92(C1)	AN/TSQ-92(D1)
Current Plans	AN/TSQ-92(2)	AN/TSQ-92(A2)	AN/TSQ-92(B2)	AN/TSQ-92(C2)	AN/TSQ-92(D2)
Automatic Switch	AN/TTC-30 →	→	AN/TTC-39 →	→	
Tech Control Facility	AN/TSC-62 →	→	AN/TSQ-111 →	→	Integrated
Teletype Center	AN/TGC-27 →	→	AN/TGC-28 →	→	
Torn Tape Relay	AN/TGC-26 →	→	---	---	
Data Proc & Display	---	485L DP&D →	→	→	→
Communication Processor	---	485L CP →	→	→	→
JTIDS ASIT	---	ASIT →	→	JTIDS Term →	→
TROPO Radio	AN/TRC-97A →	→	AN/TRC-170 →	→	
HF Radio	AN/TSC-60 →	→	→	→	
UHF Radio	AN/TRC-87 →	→	→	→	Netted Radios
SRWBR	---	---	SRWBR →	→	
Satellite Grnd Term (SGT)	---	---	AN/TSC-85 →	→	
Los Radio	---	---	AN/GRC-144 →	→	
System Control Element	---	---	AN/TYQ-16 →	→	→
AFCH Support Processor	---	---	---	Proc X →	→
Drone Control Fac Proc	---	---	---	Proc Z →	→
(F)Recon Reporting Post	---	---	---	FRRP →	→
Operation Central, ALCC	AN/TSQ-93	AN/TSQ-93(A)	AN/TSQ-93(B) →	→	→
MDT Shelter, ALCC	AN/UYA-7 →	→	→	→	→
Forecasting Module A, TWAC	TMQ-28 →	→	→	→	→
Observing Module B, TWAC	TCC-76 →	→	→	→	→
Radio Intercept Mod C, TWAC	TCC-77	TCC-77(A) →	→	→	→
Radar	TPS-67 →	→	→	→	→

NOTE: Some shelters are modified from one SCC to another to accommodate functional changes. These modifications are distinguished in the table by an arbitrary designation in parentheses following the equipment nomenclature. A description of equipment in each shelter by SCC may be found in Phase I, Task I, Final Report, OR 15,042, April 1978.

TABLE 2-3. TAC EQUIPMENT/SHELTER BY CENTER CRC/CRP

Equipment/Shelter	SCC-1	SCC-2	SCC-3	SCC-4A	SCC-4B
Operations Central, DPM	TSQ-91 →	→	→	→	→
Operations Central, AFM	TSQ-91 →	→	→	→	→
MPC, DPM	---	TYC-10, DPM →	→	→	→
MPC, AEM	---	TYC-10, AEM →	→	→	→
Tech Control Facility	TSC-62 →	→	TSQ-11 →	→	Integrated
Automatic Switch	TTC-30 →	→	TTC-39 →	→	
TTY Comm Center	TGC-28 →	→	→	---	---
Radar	TPS-43 →	→	→	DCR →	→
Tropo Radio	TRC-97A →	→	TRC-170 →	→	
HF Radio	TSC-60 →	→	→	→	
UHF Radio	TRC-87 →	→	→	→	Netted Radios
G/G Radio, Army	TCC-49/70 →	→	→	→	
JTIDS	---	---	JTIDS ASIT	JTIDS Term →	→
Satellite Ground Terminal	---	---	---	TSC-86 →	→
SRWBR			SRWBR →	→	→

TABLE 2-4. TAC EQUIPMENT/SHELTER BY CENTER TAB/TUOC/ALCE

Equipment/Shelter	SCC-1	SCC-2	SCC-3	SCC-4A	SCC-4B
Operation, TAB, ALCE, TUOC	Config A	Config B	Config C	Config D →	→
Data Source Term TUOC/ALCE	---	DST →	→	→	→
Data Set	UYA-7 →	→			
HF Radio, TUOD	PRC-153 →	→	→	→	JTIDS
HF Radio, ALCE	TRC-146 →	→	→	→	JTIDS
VHF Radio, ALCE	FM 602 →	→	→	→	→
UHF Radio, ALCE	ARC-164 →	→	→	→	→
VHF Radio, ALCE	WILCOX 807 →	→	→	→	→
HF Radio, ALCE	618T-3 →	→	→	→	JTIDS
Tropo Radio	TRC-97A →	→	TRC-170 →	→	Netted
Technical Control	TSC-62 →	→	TSQ-111 →	→	Integrated
Automatic Switch	TTC-30 →	→	TTC-39 →	→	
Satellite Ground Term	---	---	TSC-85 →	→	→
(F) Recon Reporting Post	---	---	---	FRRP →	→
SRWBR	---	---	SRWBR →	→	→
Teletype Center	TGC-27 →	→	→	→	---
Mobile Data Terminal	AN/TYC-7 →	→	→	→	→
Data Processing & Display	---	---	---	DP&D →	→
Com Processing	---	---	---	CP →	→
JTIDS	---	---	---	ASIT	JTIDS Term
PLSS Gnd Control Center	---	---	---	GCC	GCC

TABLE 2-5. TAC EQUIPMENT/SHELTER BY CENTER DASC

Equipment/Shelter	SCC-1	SCC-2	SCC-3	SCC-4A	SCC-4B
Operation Central	TSQ-93	TSQ-93(A)	TSQ-93(C)	TSQ-93(D) →	→
Data Source Terminal	---	DST →	→	→	→
HF Radio	TSC-60 →	→	→	→	
Tropo Radio	TRC-97A →	→	TRC-170 →	→	Netted Radios
UHF, VHF Radio	MRC 107/108 →	→	→	→	
Automatic Switch	---	---		ULS	Integrated
Technical Control Facility	---	---		TSQ-111	
JTIDS	---	---	---	---	JTIDS Term

TABLE 2-6. TAC EQUIPMENT/SHELTER BY CENTER FACP, ASRT

Equipment/Shelter	SCC-1	SCC-2	SCC-3	SCC-4A	SCC-4B
Radar, FACP	TPS-43 →	→	TPS-43(A) →	→	FARS
Radar, ASRT	I-Band →	→	→	→	→
Operation Central, FACP	TSC-61 →	→	TSC-61(A) →	→	→
Technical Control, ASRT	---	---	Config A →	→ }	Integrated
Technical Control, FACP	AN/TSC-53 →	→	TSC-53(A) →	→ }	Integrated
Radar Bomb Diverting Set, ASRT	TPB-1 B/C →	→	TPB-1 B/C(A) →	→	→
UHF, VHF, HF Radio	MRC 107/108 →	→	→ }	JTIDS →	→
Tropo Radio	TRC-97A →	→	TRC-170 }	JTIDS →	→

2.3.2.3 Communication interface by functional types. These signals can be grouped into five major functional types:

a. Low-Speed Serial Data - 32 Kb/s or less, e.g., Digital Voice TADIL A, B, TTY, TM Communication Control;
b. High-Speed Serial Data - Digital Groups at rates greater than 32 Kb/s, e.g., DGM;
c. Analog Voice - 4 KHz Telephone;
d. Analog Signals - Special Purpose Analog, e.g., Radar, TV, etc.;
e. Control Lines - Special Purpose Control, e.g., COMSEC, ADT, FDS, CRF, etc.;

Groupings were chosen with the design of adapters in mind. It may be possible to provide one type of adapter for each of the five functional types, thereby simplifying the design; or, more practically, a group of closely related adapters may be necessary to meet the requirements of all the signals comprising a functional type. Figure 2-15 shows the adapter functional types interconnecting with the FI through the FI standard interface.

For each of the functional types, a number of signals have been selected as representative of that type of signal. These are shown in Table 2-7.

In selecting signals, an attempt was made to cover the widest range of characteristics with as few signals as possible. These representative signals were then analyzed, and their interface characteristics were defined in Table 2-8.

Table 2-8 lists a minimum set of interface signals including the majority of the characteristics of all those TAF communication deivces of interest to the FI. In Task III, the design of the communication adapters will be based on this set of interface signal requirements.

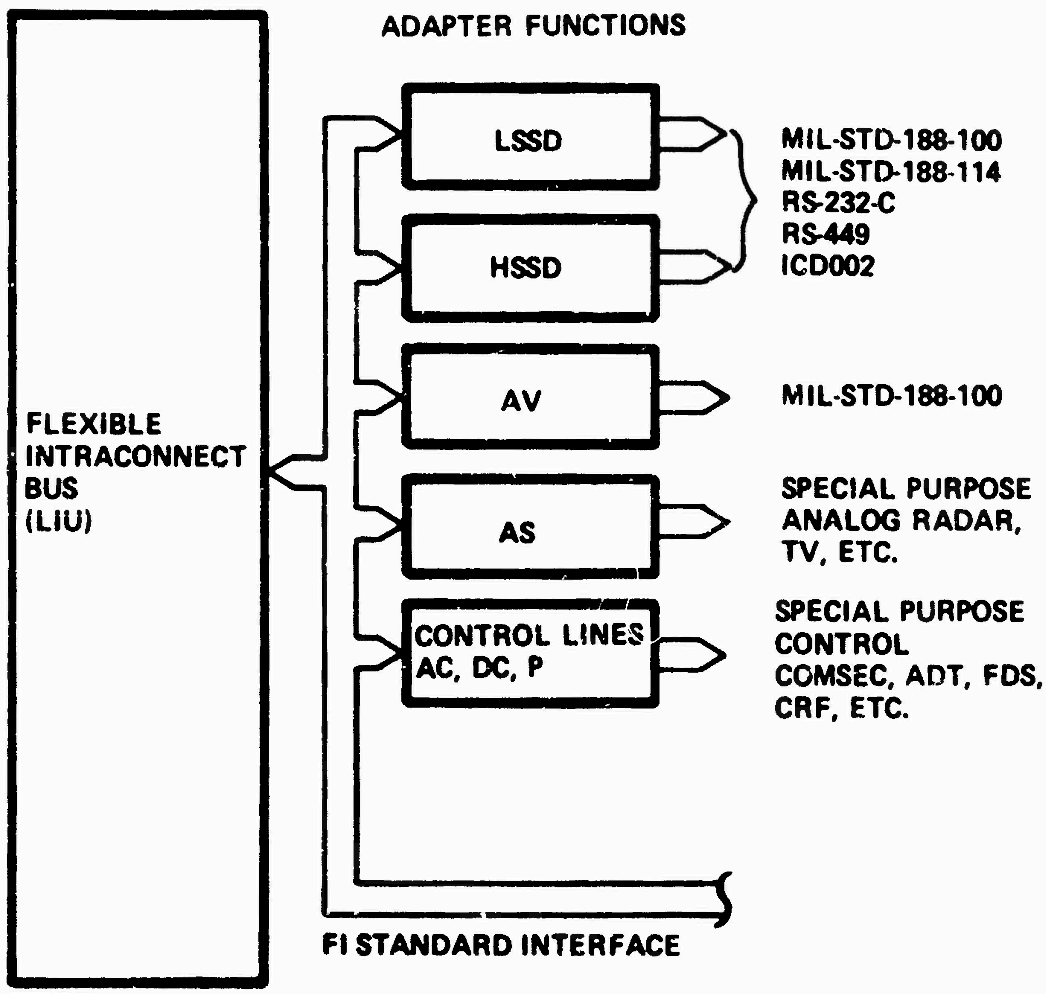


Figure 2-15. Communication adapter functions.

TABLE 2-7. COMMUNICATION INTERFACES BY FUNCTIONAL TYPES.

These are representative signal types that will be given special consideration in establishing requirements for communication adapter design in Task III.

Analog Voice

Telephone, TA-720
Telephone, TA-341
Telephone, TA-312
Modem, TADIL B
Modem, TTY, TH-85
Modem, DDL, TD-1089
20 Hz Ringer

Low-Speed Serial Data

DSVT (DNVT)
Data Adapter
Vinson, KY-58
Seeley LKG, TSEC-KG-82
Telemetry Combiner
Teletype Machine, AN/UGC-41
Voice-Frequency Telegraph
Keyer/Converter (VFTK/C)

High-Speed Serial Data

Trunk Group Mux
Master Group Mux
TED, KG-81
Loop Group Mux

Control Signals AC, DC, Pulsed

Fault Detection Subsystem
CP Status Panel (CPSP), IP-1222/T

Analog Signals

Video Signals, Height, SIF, TPS-43
Tone, 100 KHz

TABLE 2-8. CRITICAL COMMUNICATION INTERFACE CHARACTERISTICS - REPRESENTATIVE TYPES.

INTERFACE	FREQUENCY	CIRCUIT APPEARANCE	SPECIAL CHARACTERISTICS	TIME CRITICAL FEATURES
	FREQUENCY RESPONSE, BIT RATE RISE-TIME	4W-2W, BAL-UNBAL, HL-LL DUPLEX, Z, ETC.	FORMAT, MODULATION PERIOD	
ANALOG VOICE				
TELEPHONE, TA-720	4 KHz	4-WIRE, FULL DUPLEX 4-LINE OR 6 LINE TO RADIO	DTMF SIGNALLING DC PHANTOM LOOP OR AC SUPVR.	MINIMUM TIMEOUT BETWEEN SUPERVISORY SIGNALLING FUNCTIONS IS 2.0 SECONDS ASSOCIATED WITH WAITING FOR END OF SEIZE TONE, END OF RING TRIP AND OTHERS.
TELEPHONE, TA-341	4 KHz	4-WIRE, 4-LINE FULL DUPLEX	DTMF SIGNALLING DC PHANTOM LOOP OR AC SUPVR.	
TELEPHONE, TA-312	4 KHz	2-WIRE, H DPX	SIGNALLING: LOCAL BATT, 20 Hz 90V COMMON BATT, 48 VDC 60 MA	
MODEM, TADIL-A	1365 B/S, 2250 B/S	HALF DUPLEX, BAL 600 Ω	QUASI-ANALOG PHASE QUADRATURE MOD	
MODEM, TADIL-B	1200, 75, 150, 300, 600 B/S	FULL DUPLEX, BAL 600 Ω	CONTINUOUS FSM 1200 Hz(M) 2100 Hz(S) 1300 Hz(M) 1700 Hz(S) TIDP MSG FORMATS	
MODEM, DDL, YD-1000	1200, 75, 150, 300 600 B/S	FULL DUPLEX, BAL, 600 Ω	DDL MSG FORMAT, ASCII SYNCHRONOUS FSK 1200 Hz(M) 2100 Hz(S) 1300 Hz(M) 1700 Hz(S)	
MODEM, DOW DI-φ MODEM	150 B/S TO 32 KB/S	4 WIRE FULL DUPLEX LINE SIDE: UNBAL, DI-φ EQPT SIDE: BAL, NRZ	DGM FORMAT-BINARY	
MODEM, TTY, TH-85	75 BAUD	FULL DUPLEX - MIL-STD-188C	QUASI-ANALOG SYNCHRONOUS FSK 1317.5 Hz(M) 1232.5 Hz(S)	
ANALOG SIGNALS				
RADAR VIDEO	82.6 MHz BW	20 VIDEO SIGNALS	20 CHANNELS, HEIGHT BITS, VIDEO MAP, PRETRIGGER, IFF/SIC, ACP, AND OTHER VIDEO	
FSK TONE	100 KHz	2 WIRE	USE WITH TADIL-A AS TRANSMITTER CONTROL	
LOW SPEED SERIAL DATA				
DSVT(DNVT)	16/32 KB/S	4-WIRE UNBAL	CONDITIONED DI-φ IN-BAND SIGNAL	MINIMUM TIMEOUT BETWEEN SUPERVISORY SIGNALLING FUNCTIONS IS 8.5 SEC ASSOCIATED WITH RESYNC, FORCE CLEAR, AND CODE WORD RESPONSE.
DATA ADAPTER	75 B/S TO 32 KB/S	4-WIRE, FULL DUPLEX	NRZ-IN-BAND SIGNALLING	MINIMUM TIMEOUT BETWEEN SYNCHRONIZATION AND ACK FUNCTIONS IS 10 SECONDS.
LOOP GROUP MUX	32 KB/S, 256/516 KB/S 256/512 KB/S	4-WIRE, FULL DUPLEX BAL/UNBAL	NRZ-BINARY MUX	
VINSON, KY-58	16 KB/S	4-WIRE, FULL DUPLEX	DI-φ IN-BAND SIGNAL	
LKG, KG-82	150 B/S - 32 KB/S	4-WIRE, FULL DUPLEX	NRZ-BINARY	KG-82 RESYNC PROCEDURE IS NOT DEPENDENT UPON TRANSMISSION DELAYS. HOWEVER, TIMEOUT TO ALARM IF RESYNC CANNOT BE ACHIEVED MUST INCLUDE FI DELAYS OF 75 MS IN EACH DIRECTION OF TRANSMISSION.

TABLE 2-8. CRITICAL COMMUNICATION INTERFACE CHARACTERISTICS - REPRESENTATIVE TYPES (CONCL).

INTERFACE	FREQUENCY FREQUENCY RESPONSE, BIT RATE RISE TIME	CIRCUIT APPEARANCE 4W-2W, BAL-UNBAL, HL-LL DUPLEX, Z, ETC.	SPECIAL CHARACTERISTICS FORMAT, MODULATION PERIOD	TIME CRITICAL FEATURES
TELEMETRY COMBINER	150 B/S - 2 KB/S	4-WIRE FULL DUPLEX	NRZ, MUXED ASCII	
VF TELEGRAPH KEYER/ CONVERTER	75 B/S, 150 B/S VF TONES	4-WIRE, FULL DUPLEX LINE SIDE: TONES EQPT SIDE: NRZ	QUASI-ANALOG	
HIGH SPEED SERIAL DATA				
GROUP MODEM, DI-φ	72 KB/S - 4608 KB/S	4-WIRE FULL DUPLEX EQPT SIDE: BAL NRZ LINE SIDE: UNBAL DI-φ	DGM BINARY TDM	
TRUNK GROUP MUX	128/2048 KB/S 72/2304 KB/S 256/4096, 144/4608 KB/S	4-WIRE FULL DUPLEX BAL NRZ	DGM BINARY TDM	
MASTER GROUP MUX	72 KB/S TO 18.720 MB/S	4-WIRE FULL DUPLEX BAL NRZ	DGM BINARY ASYNC TDM	
TED, KG-81	72 KB/S TO 4096 KB/S	4-WIRE FULL DUPLEX	BINARY TDM	KG-81 COOPERATIVE RESYNC PROCEDURE IS NOT DEPENDENT UPON TRANSMISSION DELAYS. HOWEVER, TIMEOUT TO ALARM IF RESYNC CANNOT BE ACHIEVED MUST INCLUDE FI DELAYS OF 75 MS 14 EACH DIRECTION OF TRANSMISSION.
CONTROL SIGNALS AC, DC, P				
20 HZ RINGER	20 Hz	90V 50 MA	RING DOWN	
FAULT DETECTION SYSTEM (CNCE)	DC, UP TO 250 KHz/ LINE	SIMPLEX, 2000 LINES 16 PARALLEL LINES	FAULT/STATUS PROCESSOR CONTROL MIL-STD-1397B	
CP STATUS PANEL, IP-1222/T	15 CPS 60 CPS 100 CPS	SIMPLEX SIMPLEX SIMPLEX	10 UNIT ASCII 5, 6, 7, 8, LEVEL CODE ANY CODE UP TO 8 BITS	
AUTOMATIC ANALOG TESTER	4 KHz, UP TO 250 KHz/LINE	SIMPLEX, 4-WIRE 16 PARALLEL LINES	ANALOG VOICE LINES PROCESSOR CONTROL MIL-STD-1397B	

2.3.3 ADP equipment interface.

2.3.3.1 Objective. The objective of this analysis in Task II was to identify and characterize Input/Output (I/O) structures of Automatic Data Processing (ADP) equipment, which may be serviced by the Flexible Intraconnect (FI).

2.3.3.2 Item description. Results of Task I included consideration of the ADP equipment which would access the FI. Agreement between the customer and Martin Marietta was reached regarding the identification of the following equipment.

a. Primary: CPUs, CCD and bubble memories, disc drives, and displays.
b. Secondary: CPUs, magnetic tape transports, printers/ plotters, keyboard consoles, paper type punch/readers, card readers, and digital facsimiles.

2.3.3.3 Constraints and assumptions. A review of the system configuration concepts and conferences between the customer and Martin Marietta personnel led to the preparation of a list of the primary and secondary ADP equipment that will interface the intraconnect. Primary equipment is defined as devices whose characteristics are most representative of the majority of the devices that will have high priority for accessing the intraconnect over the period of its employment. The identified primary CPUs--IBM 360/370, PDP-10, PDP-11, and Intel 8080/85--were selected because they are the most well established and widely recognized representatives of the large computer, minicomputer, and microcomputer industries. The recent emergence of Charge-Coupled Devices (CCD) and bubble memories represents the leading edge in new memory development. Applications ranging from bulk storage using CCDs to magnetic bubble memories in intelligent terminals justify inclusion of these devices as primary equipment.

The seondary CPUs (AN/UYK-7, HM 4118, and CDC 1700) have been identified as being currently employed in the TAF C^3 facilities such as 407L and 485L. These devices will access the intraconnect in its initial employment but are not anticipated to be representative of the long-term requirement.

The list of equipment as presented in the Task II Final Report was concurred with by the customer and Martin Marietta as examples typifying the identified ADP equipment.

2.3.3.4 Analysis approach. Extensive research into vendors' literature, user's manuals, and government specifications and studies was made to gather information on the I/O characteristics of all identified ADP equipment. Essential features were compiled for examination of common characteristics. Timing diagrams of identified CPUs were generated for observance of similar handshake routines. Details were furnished in the Task II Final Report. Emphasis was placed on the I/O traits of the primary CPUs for guiding the selection of the standard interface. These features were not only analyzed from the interface point-of-view, but also for possible applications as adapters to the interface standard.

2.3.3.5 Results: An examination of essential characteristics for the identified ADP equipment resulted in the observation that a few common traits prevail at the interfaces:

a. The majority of terminals, e.g., displays, keyboards, and printers, comply with the RS-232-C/RS-449 interface standard.
b. Voltage levels for most of the equipment are either TTL compatible or -3Vdc and ground.

2.3.3.5.1 An investigation into the I/O timing features revealed a similar handshake routine for all identified CPUs, with the exception of the IBM 360/370 channel. A master-slave relationship is exhibited in the I/O transactions of these CPUs as shown in (Fig. 2-16). Here is how the master transmits data to the slave:

a. The master places data and/or address on designated lines.
b. The master sets a control line ("Master Data Ready", in this example) to signal that the data is stable and ready for acceptance by the slave. This is normally set a specified time after data/address has been transmitted in order to allow for settling of data on the lines.
c. Upon receipt of the Master Data Ready signals, the slave samples the data/address lines, and then sets another control line ("Acknowledge", in this example) to indicate to the master that the data/address has been received.
d. Upon receipt of the Acknowledge signal, the master is free to clear the Master Data Ready signal and to remove the data address from the I/O lines. This completes a data transfer from the master to the slave.

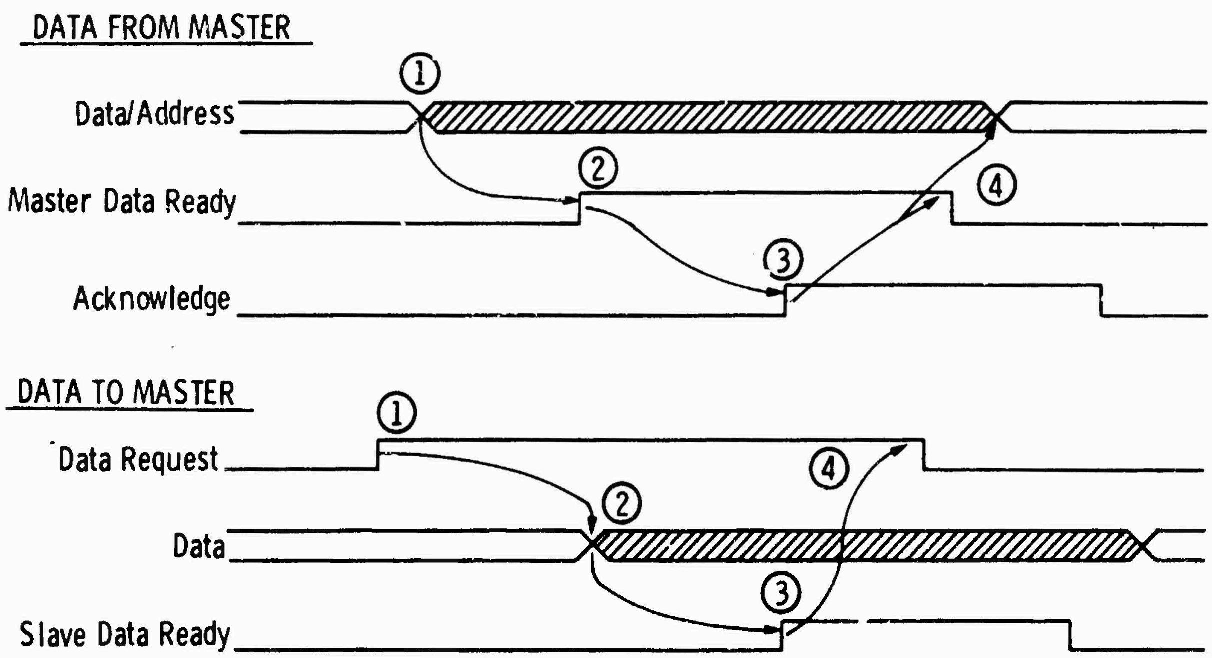


Figure 2-16. Common handshake.

2.3.3.5.2 To effect a transfer from the slave to the master, the following must occur:

a. The master sets a control line ("Data Request", in this example) to request data from the slave.
b. Sometime after receiving a Data Request, the slave puts data out on the data lines.
c. The slave sets a control line ("Slave Data Ready", in this example) to signal that the data is stable and ready for acceptance by the master. As in the case of the master sending data, a specified time normally elapses between placing data on the I/O lines and setting Slave Data Ready in order to allow for settling of the data.
d. Upon receipt of the Slave Data Ready signal, the master samples the data lines, then clears the Data Request. The slave is then free to clear the Slave Data Ready and to remove the data from the I/O lines. This completes a data transfer from the slave to the master.

Although the basic handshake as described is observed by most of the CPUs analyzed, a few deviations were found. The PDP-10 does not require an Acknowledge signal when sending data to a peripheral. A device communicating with the CDC 1700 can substitute a Reject signal for the Acknowledge or Slave Data Ready signals if it cannot receive or transmit data. Several of the CPUs supplement these fundamental signals with added control signals. The CPU does not function as the master in all cases. Although the CDC 1700 and PDP-10 act as the master during their I/O transactions, the peripherals play the master role when communicating with the HM-4118 and AN/UYK-7. The PDP-11 assigns master status to a device on its UNIBUS with software.

2.3.3.6 Conclusions. From this study, it is apparent that the interface standard should exhibit a master-slave relationship in the timing and handshake routine between an external device and the interface to the FI. Characteristics demonstrated by CPUs such as the Intel 8085 and PDP-11 should form the base for such a standard.

2.4 Information flow analysis.

The objective of the requirement studies was to classify and enumerate the information flow within the centers of the TAF. This definition establishes the traffic capacity and flexibility requirements for the Intraconnect. This subsection describes the approach followed in defining the traffic load and presents the results of this analysis for each of the centers defined in the preceding SCC descriptions.

The approach for developing the information flow analysis was to define each of the internodal networks for SCC-1 and to use the traffic summary data and routing plan information from Annex II of the TAFIIS Master Plan to allocate communications traffic to the various nets. The internodal traffic was then analyzed with respect to the various nodal communications equipment and, combined with the information flow that originates and terminates within the node, to determine the total intranodal traffic flow. The information flow developed for SCC-1 was used as a baseline to analyze the traffic for each of the other SCCs.

2.4.1 Network development rationale.

2.4.1.1 Transmission network. In SCC-1, the TAF is deployed at 10 407L equipped nodes and eight tactical air bases. Primary communication for the deployment is provided by a transmission network of interconnected point-to-point radio paths. The transmission network is shown in Figure 2-17. The configuration of this transmission network will remain constant for SCC-1 and SCC-2, except that SCC-1 does not include the AUTODIN traffic to or from the

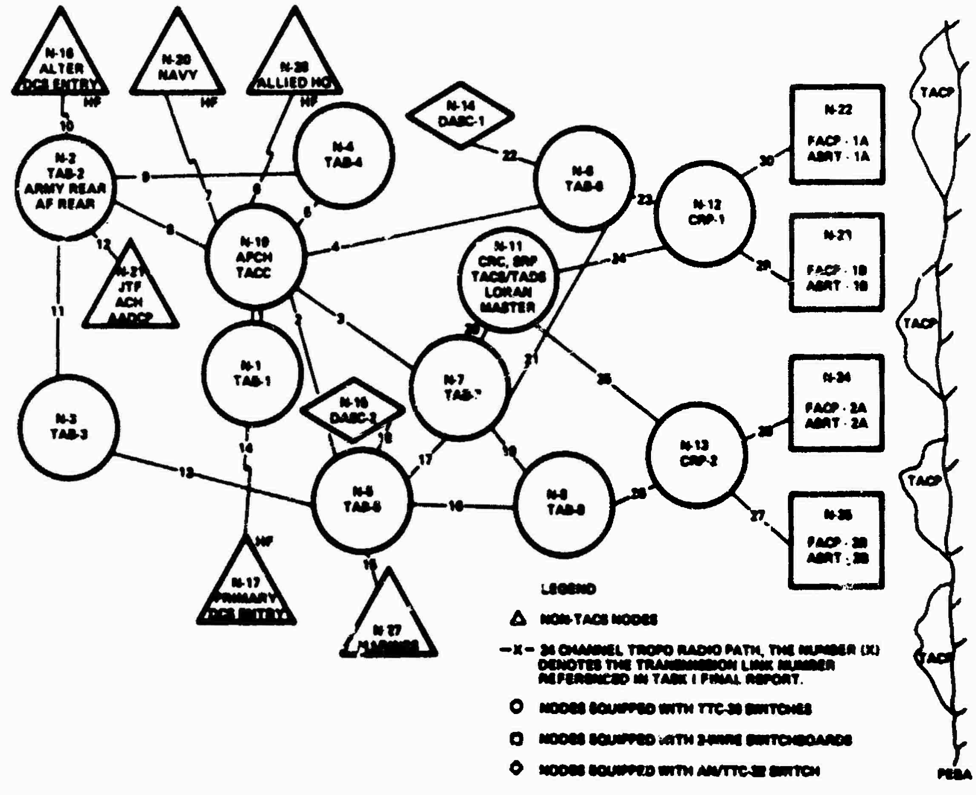
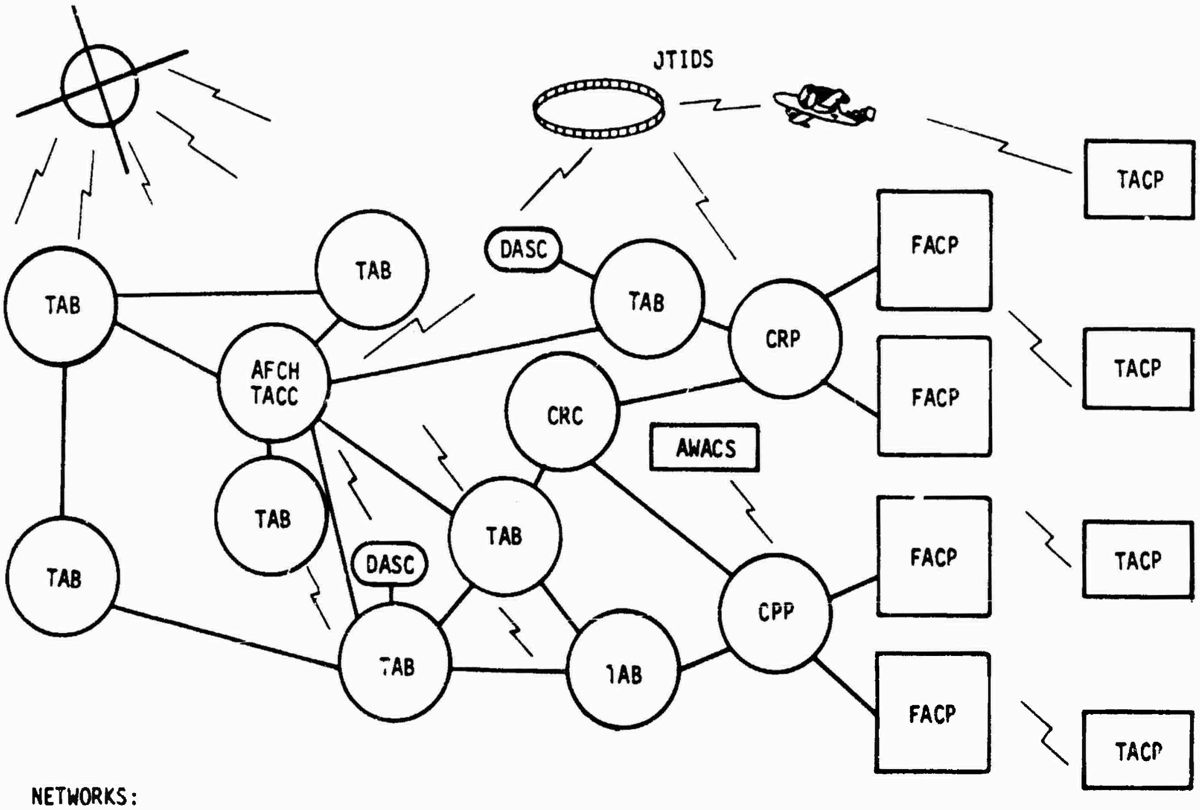


Figure 2-17 TAFIIS master plan - transmission network.

DCS. For SCC-1 and SCC-2 the terrestrial transmission system is analog, while in SCC-3 and SCC-4 the terrestrial transmission system is digital. The HF transmission system interfacing the deployed forces with the DCS, Navy, Marines, etc., in SCC-2 will be replaced by satellite links (Fig. 2-18). This study assumes that these networks will eventually be supported by an advanced JTIDS network as illustrated in Figure 2-18, thus eliminating the need to deploy all of these equipments.



NETWORKS:

SATELLITE - TAB AND AFCH TO INTERFACING UNITS NAVY, MARINES, DCS, ALLIED HQ, JTF
JTIDS - TAC DATA NETS, G-A-G NETS
TROPO/MICROWAVE - CIRCUIT SWITCH NETWORK, DATA NETWORK

Figure 2-18. Transmission networks SCC-3 and -4.

Although this study identifies the advanced JTIDS capability, it should be noted that the concept and capabilities of the Flexible Intraconnect will be designed to support either the JTIDS or the existing HF, UHF, and VHF equipments.

2.4.1.2 Circuit switch network. The circuit switch network as defined by the TAFIIS Master Plan is shown in Figure 2-19. The primary routing plan for this network configuration is contained in the Phase I Final Report Table 4. This routing plan is designed for use with the AN/TTC-30 and the AN/TTC-32.

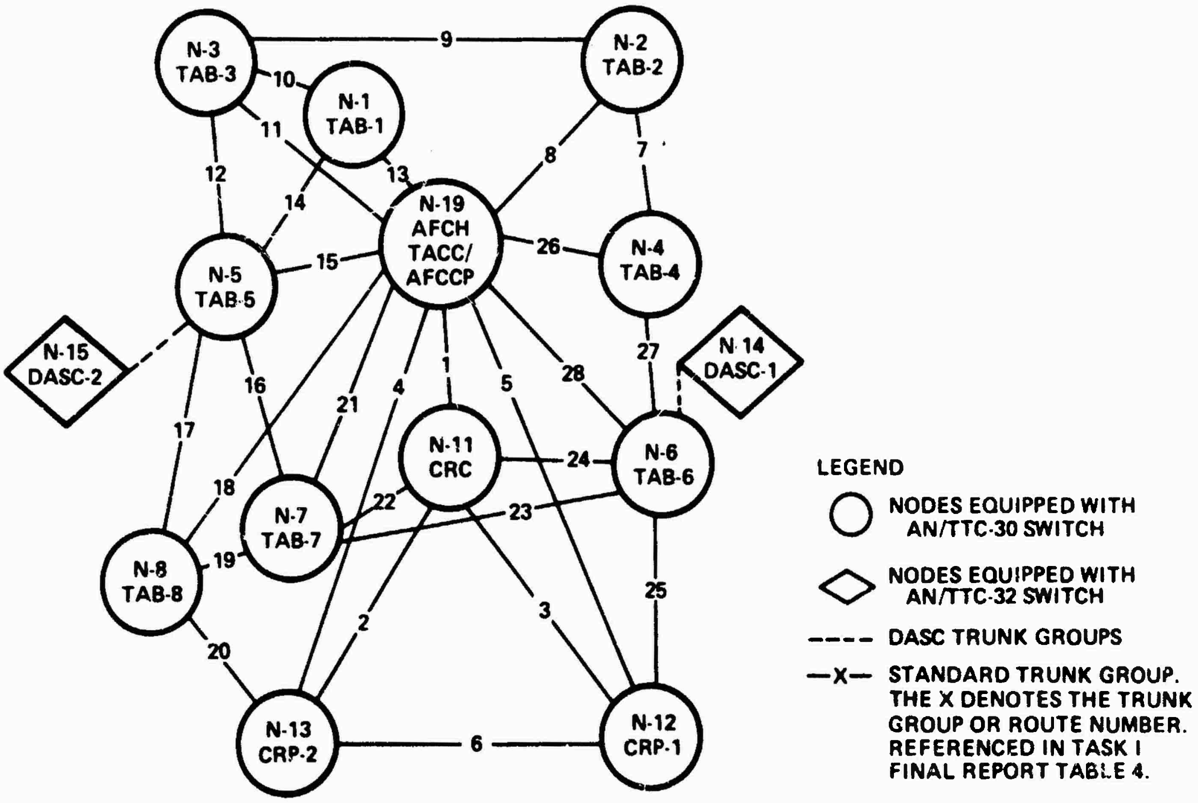


Figure 2-19. TAFIIS Master plan circuits switch network.

The traffic between switching centers is determined by totaling the traffic between nodes as offered to a trunk group. The traffic offered to a trunk group is defined by the routing plan. The TAFIIS Master Plan provided a summary of the traffic and of the circuits required per trunk group.

The circuit switch network configuration remains constant throughout this study, but its character and features change with the use of digital terrestrial and satellite transmission systems, and with the evolution from AN/TTC-30 switches in SCC-1 and SCC-2 to the AN/TTC-39 for SCC-3 and SCC-4A, and to a switch system in SCC-4B that is integrated into the intraconnect transmission system.

2.4.1.3 Teletypewriter, weather, and data networks. The transmission network also supports common user, TTY, weather, and data nets. The TTY net is depicted in Figure 2-20 and the weather net in Figure 2-21. Data nets involve the connectivity of special-purpose data circuits, which are discussed on a node-by-node basis in subsection 2.5.

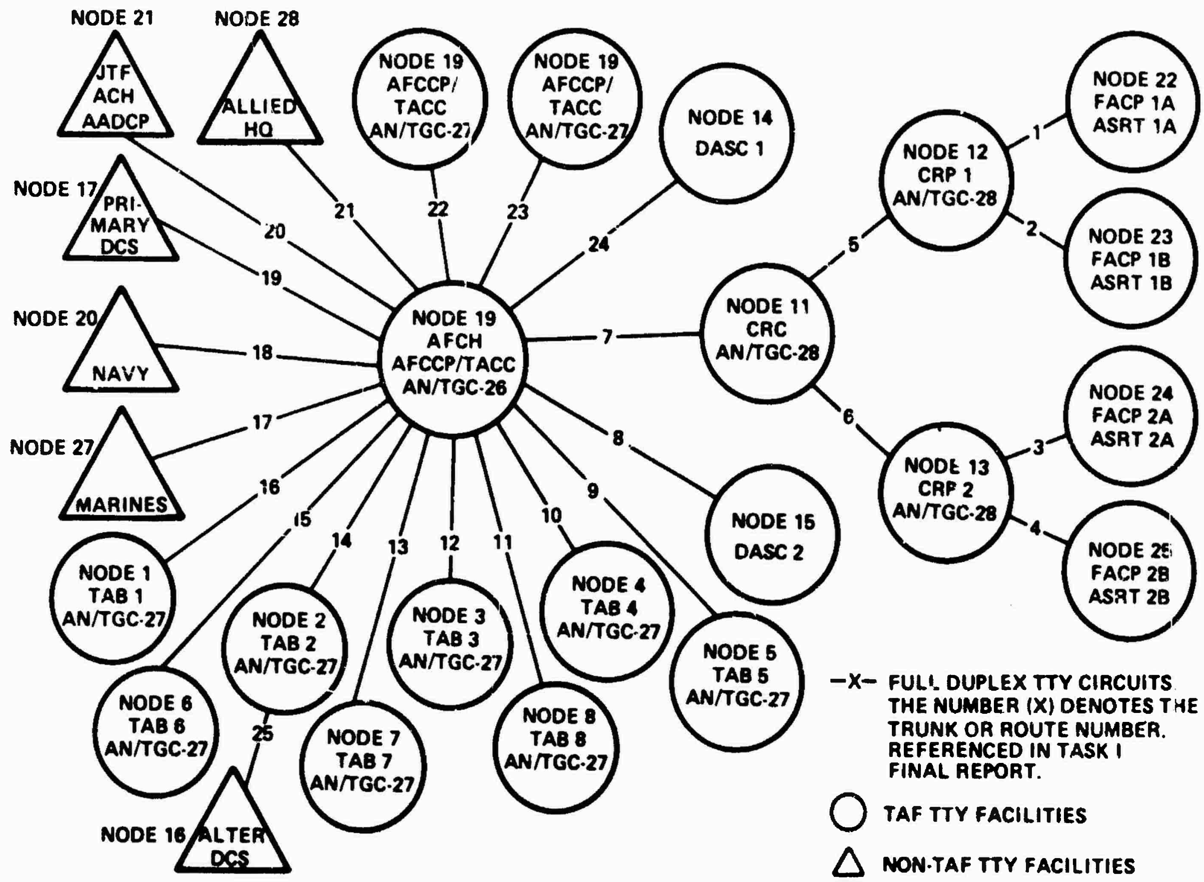


Figure 2-20. TAFIIS master plan - teletype network.

In all concepts except SCC-4B, the TTY, and data traffic continue to be carried in the basic networks as described in Figures 2-20 and 2-21. It is assumed that the addition of the AN/TYC-13 and digital data links to SCC-4B will not change circuit requirements. In SCC-4B, each node and/or TAC element will be equipped with a processing center having multiple processors, memories, and mass storage devices interconnected by a bus system. This bus system allows all processors to access any of the memories or storage devices.

The processing center was assumed to have the inherent capability to: 1) Act as a packet switch for data messages; 2) use the circuit switch function of the intrasite bus to establish communication between processing; 3) transfer data from the data bus of one center to another, and 4) transfer the problem-solving responsiblity of one center to another.

Radio broadcast network. The 407L TACS communications network provides the communication channels for a control network and also for the command, administrative, and logistics network. The control networks provide communication from the AFCCP/TACC throughout the direct air support and aircraft control and warning subsystems of TACS. The DASC and AFCH/TACC are primarily concerned with the control network. The following paragraphs describe the control network capabilities, which consist of:

a. Air Force air-request nets;
b. Tactical air direction nets;
c. Tactical air control nets;
d. Airlift control nets; and
e. In-flight report nets.

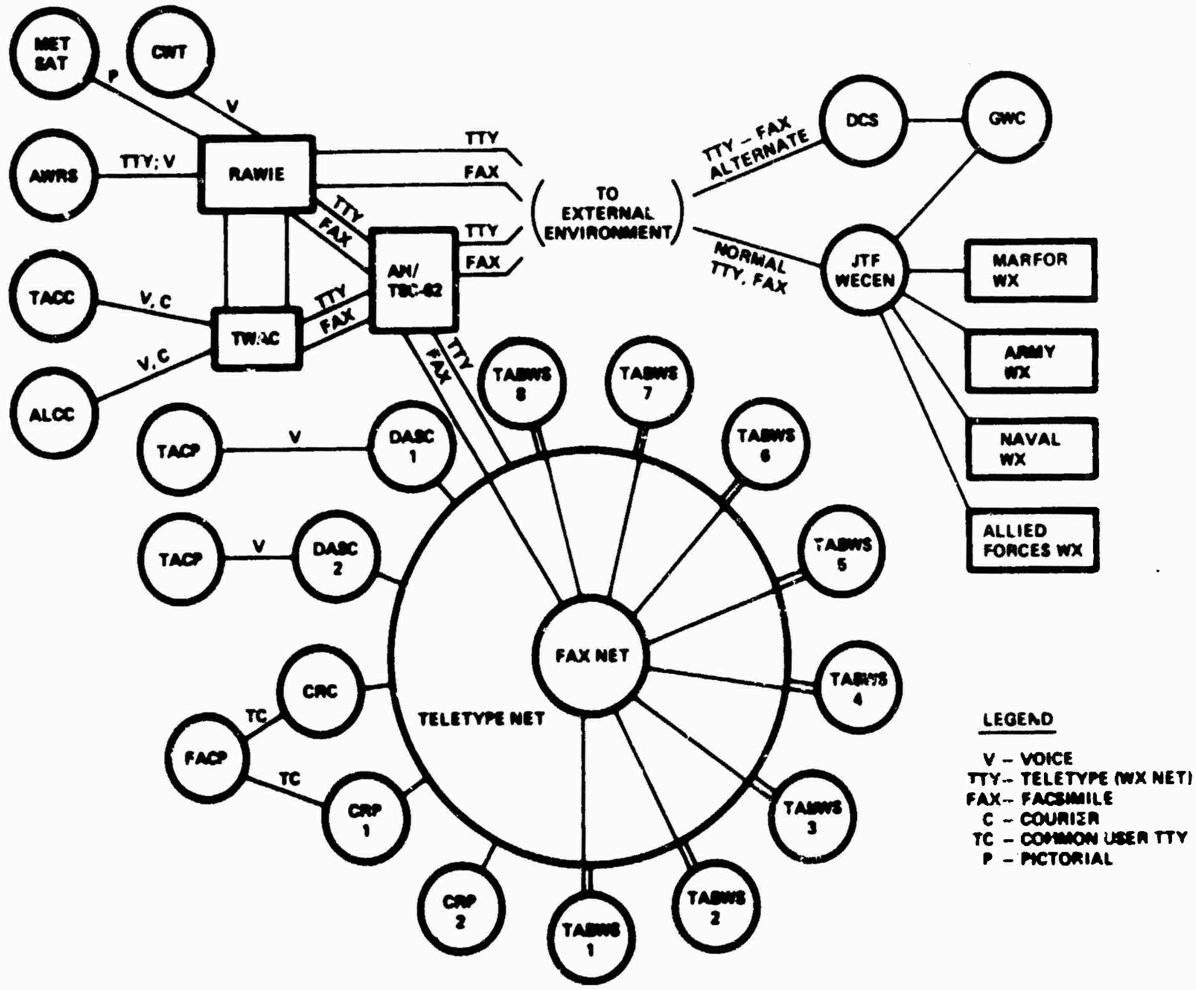


Figure 2-21. TAFIIS master plan
weather system teletype, facsimile networks.

2.4.1.5 Worst-case traffic loads. One of the most important results of this analysis was the definition of the worst-case traffic load for the intra-shelter and intershelter intraconnects. These values determine the maximum traffic capacity handling requirements for the intraconnect designs for each application. It was determined early in the analysis that the maximum ADP traffic load occurs at the CRC for both intrashelter traffics. Maximum voice traffic loading occurs at the TACC for both intrashelter and intershelter cases. The following is a summation of total traffic requirements in terms of bus-bit rate for the two applications. These values are used in the analyses and for selecting a recommended concept. The results are summarized in Table 2-9.

TABLE 2-9 BUS CAPACITY REQUIREMENTS SUMMARY

	SCC-4A		SCC-4B	
	Intra-Shelter*	Inter-Shelter*	Intra-Shelter*	Inter-Shelter*
Voice Communications (TACC)	1.02	18.24	0.77	6.3
ADP (CRC)	87.0	45.0	91.0	72.0
Margin	8.8	6.3	9.2	7.8
Overhead	30.0	30.0	45.0	45.0
Total	126.82	99.54	145.97	131.1

*Capacity in MB/s @ kb/s per channel

The results were based on the following assumptions: A voice digitization rate of 32 kb/s (CVSD); integration of circuit switch, CRF, and FI switching functions in SCC-4B; a possible co-location of CRC and TACC.

If the voice digitization rates were 64 kb/s and the integration concepts do not take place, another set of worst-case conditions exist. These are shown in Table 2-10. The maximum bit-rate requirement is 149.4 Mb/s on the intershelter bus in SCC-4B, which is not appreciably different from the 145.9 Mb/s found in the earlier analysis. It should be noted that the difference between the two would be considerably greater if a more conservative figure had been used for the additional overhead required for integration functions. Fifteen Mb/s were added in SCC-4B over the 30 Mb/s in SCC-4A to account for this. After an analysis of integration concepts, Section 5.3, it appears that a 5 Mb/s addition would be more realistic, and the maximum requirements would then be 135.97 Mb/s. Based on this, the comparison between the requirements for the FI using 32 kb/s CVSD and an integrated switching concept, i.e., 135.97 Mb/s and one using 64 kb/s PCM and a non-integrated switching concept, i.e., 149.4 Mb/s, is more significant. But in either case, a maximum FI requirement of 150 Mb/s is adequate.

TABLE 2-10 MAXIMUM FI LOAD REQUIREMENTS

Intrashelter Bus	@32 kb/s	@64 kb/s
Voice CRC (SCC-4B)	0.5 Mb/s	1.0 Mb/s
ADP CRC (SCC-4B)	91.0 Mb/s	91.0 Mb/s
Margin:	9.2 Mb/s	9.2 Mb/s
Overhead:	30.0 Mb/s	30.0 Mb/s
Total	130.7 Mb/s	141.2 Mb/s
Intershelter Bus		
Voice TACC (SCC-4B)	18.2 Mb/s	36.4 Mb/s
ADP CRC (SCC-4B)	72.0 Mb/s	72.0 Mb/s
Margin:	9.0 Mb/s	11.0 Mb/s
Overhead:	30.0 Mb/s	30.0 Mb/s
Total	129.2 Mb/s	149.4 Mb/s

2.4.1.5.1 Intrashelter maximum traffic load. Voice communication: The TACC operations central was used to establish the intrashelter voice communication requirements. In SCC-4A the intrashelter voice traffic can be carried on 32 time-shared circuits operating at 32 kb/s each, resulting in a capacity requirement of 1.024 Mb/s. Considerable reduction in voice circuit requirements for the intrashelter bus is seen in SCC-4B because the circuit switch is integrated with the bus. In SCC-4B, the equivalent of 24 circuits access the intraconnect bus, requiring 768 kb/s capacity.

ADP - The ADP traffic requirements are based on the CRC. In determining intrashelter requirements, the maximum load occurs when the operations central (AN/TSQ-91) and MPC (AN/TYC-10) are collocated. In both SCC-4A and 4B the processors are interconnected by a high-rate bit parallel bus. Each processor is capable of transferring data at 18 Mb/s onto the bus. This load could reach a peak of 36 Mb/s. Display traffic accessing the bus requires 51 Mb/s. The total ADP traffic is 87 Mb/s. In SCC-4B, greater use of the ADP facilities is expected; 4 Mb/s is allowed for this growth, for a total of 91 Mb/s.

2.4.1.5.2 Intershelter maximum traffic load. Voice communication: The greater voice traffic load on the intershelter bus was determined to occur at the TACC center, including the AFCH, ACIC, and other collocated facilities defined by the SCCs. The intershelter requirement in SCC-4A of 18.24 Mb/s came from 570 32 kb/s circuits. The reduction in SCC-4B to 6.3 Mb/s is due largely to the integration of circuit switch functions onto the bus.

ADP - For the intershelter requirements, the maximum load is experienced at the CRC when the MPC is separated from the operations central and processor-to-processor traffic uses the intershelter bus. The display controllers are not on the intershelter bus since they access their associated processors directly, and any intershelter display exchanges will appear on the intershelter bus as processor-to-processor traffic. In SCC-4A, the intershelter traffic requirement was determined to be 45 Mb/s. Eighteen Mb/s is allocated to the processor-to-processor exchange between MPC and operations central processors, 2 Mb/s to service communications traffic and digitally coded radar requirements, 5 Mb/s for consoles that may be located remotely from the operations central, and 20 Mb/s to a computerized combined IDR facility (yet undefined) that will require access to a theaterwide ID data base.

In SCC-4B, this traffic is estimated to increase to 72 Mb/s - due in part to increased control functions required for coordination and synchronization of the netted radars and radios introduced in this scenario, and in part as a contingency for new facilities with undefined loads, which are likely to be collocated and computerized such as drone control facilities, ground control centers for GTSSC functions, forward reconnaisance reporting posts, and others.

2.4.1.5.3 Overhead and margin. In all four bus applications, additional capacity is required for overhead functions and margin (Table 2-9).

A design margin of 10 percent of the rate estimated for information, i.e., voice and data, has been added to account for inaccuracies in approximations made in the traffic analysis.

In SCC-4A, 30 Mb have been alloted to basic overhead functions such as framing, synchronization, formatting, polling, device status, data ID, call establishment, and others.

In SCC-4B, the required overhead increases to 45 Mb/s because of the integration of switching and technical control functions with the bus. These require additional capacity for call processing and special features.

At this point, it has not been determined to what degree these functions will become a part of the bus design. Some of the functions such as signaling, supervision, and conferencing will be performed by the bus while others such as traffic load control and quality monitoring may be performed by peripheral equipment and simply controlled or recognized by the bus. This determination and, consequently the bus capacity required for it, will be made in a later task in the study.

2.4.1.5.4 Conclusion. A highway bit rate of approximately 150 Mb/s is a good design goal for both intershelter and intrashelter applications.

2.4.2 Analysis of TAF nodes. The traffic study was concentrated on the nine major nodes of the TAC system. These nodes encompass a range of requirement variations that include any potential application of the Flexible Intraconnect in the TAC. Traffic requirements for these nodes are defined separately for each of the five system configurations.

Traffic estimates include internodal traffic, intershelter traffic and, in some cases, intrashelter traffic, i.e., traffic flowing between devices within a common shelter.

Intrashelter traffic was not enumerated for SCCs 1, 2, and 3 because it was assumed that the intraconnect would not be installed within existing shelters due to space limitation and interface incompatibilities. Intrashelter traffic was defined for SCC-4A and -4B where the assumption was that much of the equipment would be designed initially with compatible interface.

Traffic requirements are identified in terms of number of circuits, erlangs of traffic, bandwidth, and bit rate. In reviewing these data, it is important to realize that achievement of a high accuracy in estimating the quantity of traffic for each and every circuit was not an objective of the analysis. The objective was to derive an approximation of the maximum total traffic load for each category of traffic (communications or ADP) for each of the 10 nodes in each of the five SCCs. The traffic loads obtained by this approach are adequate for sizing the capacity requirements of the Flexible Intraconnect.

The results presented here are a summary of a more detailed analysis contained in the Phase I Task I Final Report. A brief description of the traffic features at each center is presented with qualifying factors pertaining to the analysis. The Phase I study should be consulted for supportive information. Table 2-11 is a summary of the number of circuits and the traffic carried for each of the centers and all SCCs. Table 2-11 is useful for obtaining a broad view of the traffic loads at all the centers in relation to each other. However, the generality masks the more useful data available from the study. Table 2-12 presents a further breakdown of traffic data for SCC-3 and SCC-4A. In this table, erlangs of traffic are used to determine the equivalent number of digital circuits required to carry the total voice traffic. It was assumed that the TRI-TAC family of digital group rates would be used to carry trunk groups, and that loops would be digitized at 32 kb/s. Group size was derived for each link from the tables of the Task I report. It was further assumed that the smaller centers would not be implemented with an EI but would use a concept of interconnected SIUs. This means that the 30 Mb/s allocated for message overhead in the full FI would be reduced to 10% in these implementations. The operation of the SIU concept is discussed in Section 5.0 and 7.0. It should be noted that Table 2-12 does not itemize intrashelter traffic. This is not considered necessary for the SIU implementation in the smaller centers. The intrashelter traffic analysis, done for the CRC and TACC to determine the maximum bit-rate requirement for the local intraconnect can be projected to the DASC, if necessary.

TABLE 2-11. TRAFFIC SUMMARY

	System Configuration Concept									
	1		2		3		4A		4B	
	Circuits	Traffic (ERLANGS)	Ckts	TFC ERL	Ckts	TFC ERL	Ckts	TFC ERL	Ckts	TFC ERL
AFCH/TACC	790	278.4	940	280.0	1035	281.32	897	281.22	674	214.35
TWAC	29	2.2	42	2.2	50	2.2	--	--	30	2.2
ALCC	50	4.8	67	4.8	47	2.9	21	2.9	41	4.8
TUOC	14	2.6	31	2.6	37	2.6	--	--	15	2.6
ALCE	9	.45	9	.45	9	.45	9	.45	9	.45
CRC/CRP	321*	71.2*	303	72.4	303	72.8	307	72.69	326	50.3
FACP	46	2.8	46	2.8	53	4.0	29	3.0	31	3.0
ASRT	26	0.4*	26	0.4*	41	4.2	27	4.2	27	4.2
DASC	111	22	111	22	89	7.6	68	7.6	78	14.8

* Radar Signals
Not Included

TABLE 2-12. SCC-3, SCC-4 INTERSHELTER TRAFFIC SUMMARY

Center	SCC-3						SCC-4A					
	Com TFC (ERL)	32k Chans of DIG GRP Equivalent	Total 4-Wire Circuits	Equivalent BR (Mb/s)			Com TFC (ERL)	32k Chans of DIG GRP Equivalent	Total 4-Wire Circuits	Equivalent BR (Mb/s)		
				Com	ADP	Total				Com	ADP	Total
TACC/AFCH	280	548	1035	17.5	36	88.5 Δ	281.2	570	897	18.24	48	102.84 Δ Δ
TWAC	2.2	31	50	0.992	1	Δ 2.39 Δ	2.2	31	50	0.992	1	Δ Δ 2.39
ALCC	2.9	15	47	0.480	1	Δ 1.776	2.9	20	37	0.640	1	Δ 1.968
TUOC	2.6	20	37	0.640	1	Δ 1.968	2.6	20	37	0.640	1	Δ 1.968
ALCE	0.45	9	9	0.288	--	Δ .345	0.45	9	9	0.288	--	Δ 0.345
CRC/CRP	72.8	356	303	11.39	30	75 Δ Δ	72.69	346	307	12.28	45	Δ 92
FACP	4.0	21	53	0.672	--	Δ Δ 0.806	3.0	25	29	0.800	--	Δ 0.96
ASRT	4.2	21	41	0.672	--	Δ Δ 0.806	4.2	22	[illegible]	0.704	--	Δ Δ 0.844
DASC	7.6	48	89	1.536	--	32.5 Δ	7.6	64	68	2.048	--	35.25 Δ

Δ Includes Total Overhead
10% Margin
30 Mb/s Message Overhead

Δ Does not Include TV or
Radar that will use
Separate FDM Ckts

Δ Implemented with SIU's (no E1)
Margin 10%
Overhead 10%

2.4.2.1 System Configuration Concept No. 1. The networks specified in the TAFIIS Master Plan were used as definition of a basic 407L configuration.

2.4.2.1.1 AFCH/TACC Traffic Loading Analysis for SCC-1. The traffic analysis defines the communication requirements for a maximum configuration of the AFCH/TACC. All network circuit and equipment configurations used in analysis were extracted from the TAFIIS Master Plan. The analysis defines the communication requirements for the AFCH/TACC in the baseline system configuration, SCC-1 Fig. 2-2.

A summary of the AFCH/TACC traffic is presented in Tables 2-11 and 2-12 which define the number of circuits required to handle the traffic and, where applicable, the erlangs of traffic offered to those circuits. Since this study was scenario-dependent, the traffic and circuits are referenced to the circuit switch, TTY, weather, and transmission networks.

Traffic on the trunk groups between switching centers was calculated using the routing plan from the TAFIIS Master Plan (Table 4 of the Phase I Report). The number of circuits on a trunk group was determined from the erlang B full-available tables assuming a blocking probability of one call in a hundred. Where traffic generated by a collocated center, e.g., TWAC, has been identified, this traffic is included in the traffic that the transmission equipment must carry.

2.4.2.1.2 TWAC traffic loading analysis for SCC-1. The TWAC, normally deployed at the TACC operating location, consists of two functional elements: The TACCWE and RAWIE. Since the voice, TTY, and facsimile circuits are routed through the TACC communication facilities, the intersite traffic loading is included in the AFCH/TACC traffic analysis. The TWAC is located at node 19 in the transmission network from the TAFIIS Master Plan and interfaces with the TAF elements as shown in Figure 2-3.

The traffic analysis defines the communication load requirements for the maximum configuration, including the addition of a weather radar that is normally part of the TABWS but could be deployed at the TWAC under certain conditions. Otherwise, the baseline network, circuit, and equipment configurations used at the TWAC were extracted from the Master Plan and Tactical Weather Systems Operations Regulation ASWR 55-9, dated 25 August 1975.

The baseline equipments are interconnected as shown in Figure 2-3. Each interconnecting link is identified with an alpha character. This reference is used in the tabulation of the intracenter traffic requirements. Tables 2-11 and 2-12 summarize the traffic at the TWAC.

2.4.2.1.3 ALCC traffic loading analysis for SCC-1. The baseline configuration for the ALCC described in subsection 2.2.1 consists of an AN/TSQ-93 and an AN/UYA-7, which are tenents of the TACC. Communication support is derived from the resources of the TACC.

Traffic loading is summarized in Tables 2-11 and 2-12, while Figure 2-6 shows link connectivity.

2.4.2.1.4 TUOC traffic loading analysis for SCC-1. The present TUOC configuration is limited to a manual mode of operations making use of TAB communications-electronic facilities provided by the tactical air base to supplement their intrasite communication needs. SCC-1 has provided some standardization to the hardware concept, using the communications equipment organic to the facility depicted in the TAFIIS Master Plan and as shown in Figure 2-3.

The intershelter communications traffic is summarized in Tables 2-11 and 2-12, which define the number of circuits required to handle the traffic and terminate the TUOC subscriber terminal consisting of a small amount of equipments. No intrashelter analysis was performed.

2.4.2.1.5 ALCE/CCT traffic loading analysis for SCC-1. ALCE is a TACS element through which the AFCC maintains control of assigned airlift forces. the ALCE is subordinate to the ALCC. Traffic circuits for the ALCE in SCC-1 are shown in Figure 2-6. The CTT is subordinate to the ALCE.

Communication circuits for the ALCE are all self-contained and organic to the ALCE shelter. Landline connectivity to the TAB switched-voice network is used for backup communications with the ALCC (when available) and for coordination with other base activities. The AN/UYA-7 data sets, associated AN/TRC-146 radios, and various G/A/G radios are located in the shelter.

CCT communications support is provided by an AN/MRC-107 and -108 mobile radio central equipped with an AN/UYA-7 data set and associated AN/TRC 146 radio.

2.4.2.1.6 CRC/CRP traffic loading analysis for SCC-1. The CRC contains the prime-control radars of the TACS and supervises the activities of subordinate radar elements. It collects information on all air activities within radar and radio range using organic and subordinate element equipment. After evaluation, this information is disseminated throughout the TACS. Figure 2-7 identifies the intershelter links of the CRC.

Analysis of the CRC traffic flow was documented in more detail than some of the other centers analyzed since it was used as the model for the architecture analysis of alternative intraconnect concepts.

Tables 2-11 and 2-12 summarize CRC traffic analysis results, while more detailed data are listed in Table F-2 and F-3, Appendix F of the Final Report.

Traffic on the trunk groups between switching centers was calculated using the routing plan from Table 4 of the Phase I Final Report. The number of circuits on the trunk group was determined from the erlang B fullavailability tables assuming a blocking probability of one call in a hundred. Tables 2-13 and 2-14 list the characteristics of radar signal flow between the AN/TPS-43 and AN/TSQ-91.

The traffic flow for a stabilized FACP, as shown in the TAFIIS Master Plan, is summarized in Tables 2-11 and 2-12. The traffic load between the AN/TSC-53 and TRC-97 includes the traffic imposed by the collocated ASRT. Figure 2-8 shows the intershelter connectivity for each link.

TABLE 2-13. DIGITAL WEIGHT SIGNAL CHARACTERISTICS

VIDEO AND TRIGGER SIGNAL CHARACTERISTICS*

SIGNAL TYPE	PULSEWIDTH (μs)	RISE TIME (μs)	FALL TIME (μs)	BANDWIDTH (MHz)
Pretrigger	2 ±0.5	0.50	0.50	1.2
IFF/SIF Composite	0.45 ±0.1	0.10	0.20	5.0
MTI Gated Video	0.5	0.15	0.20	4.0
Search Video	0.5	0.15	0.20	4.0
Synthetic Video	4 ±0.5	1.00	1.20	0.6
ACP	5 ±2.0	1.00	1.25	0.6
North Mark	5 ±2.0	1.00	1.25	0.6
TOTAL BANDWIDTH REQUIRED = 17.0 MHz				

*Extracted from MITRE WP-5629, March 77, "Information Bus System for Tactical Operation Center".

TABLE 2-14. CHARACTERISTICS

DIGITAL HEIGHT SIGNAL CHARACTERISTICS

SIGNAL TYPE	PULSEWIDTH (μs)	RISE TIME (μs)	FALL TIME (μs)	BANDWIDTH (MHz)
Height Bit 1	4 ±0.5	0.5	0.5	1.2
2	4 ±0.5	0.5	0.5	1.2
3	4 ±0.5	0.5	0.5	1.2
4	4 ±0.5	0.5	0.5	1.2
5	4 ±0.5	0.5	0.5	1.2
6	4 ±0.5	0.5	0.5	1.2
7	4 ±0.5	0.5	0.5	1.2
8	4 ±0.5	0.5	0.5	1.2
Height GO Bit	2 ±0.5	0.5	0.5	1.2
TOTAL BANDWIDTH REQUIRED = 10.8 MHz				

*Extracted from MITRE WP-5629, March 77, "Information Bus System for Tactical Operation Centers".

2.4.2.1.7 FACP traffic loading analysis for SCC-1. FACP performs mobile radar surveillance and control of tactical air missions, hands off aircraft to (FACs), and augments CRC/CRP radar coverage. It is capable of controlling tactical missions under poor weather conditions. The traffic analysis defines the communication requirements for the FACP, including the G/G communications load of the collocated ASRT.

2.4.2.1.8 ASRT traffic loading analysis for SCC-1. In SCC-1, the ASRT is collocated with the FACP, sharing the AN/TRC-97A for communication with the TWAC for weather information, the CRC for control and relay of FRAG orders, and the CRP/CRC for track handover coordination. Figure 2-9 depicts the ASRT communication interfaces and shows the major elements of the ASRT with communication links identified for reference to the traffic loads summarized in Table 2-11 and 2-12. Control of the mission aircraft is via UHF radio, using voice and/or tones for final approach guidance.

2.4.2.1.9 DASC/TACP traffic loading analysis for SCC-1. The 407L communications system provides the voice and TTY media for the transmission, reception, and termination of operations, logistics, intelligence, weather, and administrative traffic between the DASC and other TACS operating locations. The communication networks (subsection 2.1) provide G/G voice communication service to the DASC. A manual electronic switchboard (AN/TTC-32) is provided as an integral part of the AN/TSQ-93 to support both intersite and intrasite switching functions. The operators are also provided with foreign exchange lines from the nearest AN/TTC-30.

The intrasite traffic requirements for SCC-1 are also summarized in Tables 2-11 and 2-12, which is referenced to the intershelter connectively described in Figure 2-10. The common-user traffic is defined in terms of both circuits and traffic load (in Erlangs).

The communications equipment serving the DASC is connected to the operations center with each link returned with a letter to document the intranodal traffic requirements.

In this analysis, we have assumed that each user at the DASC (in SCC-1) is provided with an individual circuit to the AN/TTC-32 and also a circuit to the nearest AN/TTC-30.

2.4.2.2 System Configuration Concept No. 2. SCC-2 adds several new equipments and capabilities to the basic 407L configurations. The approach taken in estimating the traffic for SCC-2 was to hold the traffic estimate for SCC-1 constant and add to it the traffic carried by the equipments added in SCC-2.

2.4.2.2.1 AFCH/TACC traffic loading analysis for SCC-2. SCC-2 adds the 485L, TIPI, JTIDS, PLSS, DCS, and WWMCCS function to the basic 407L system of SCC-1. The basic AFCH/TACC configuration will be changed by the addition of the JTIDS ASIT, the AN/TYC-7 MDT, and the 485L DP&D equipment. The 486L equipment includes a data processing and display shelter, a communications processor shelter, display consoles, and large-screen displays.

Parallel data circuits are provided to exchange data between the 485L communications processor shelter and the DP&D shelter. Similar parallel circuits are provided to connect display equipment in the TACC or AFCH. Any collocated centers, e.g., TWAC or ALCC, with 485L-type consoles are connected by similar parallel data circuits.

2.4.2.2.2 TWAC traffic loading analysis for SCC-2. The TWAC configuration is modified in this concept by the addition of a TDU and an MDEU that interface directly with the TACC data processing system and give the TACC direct weather data interface.

This change in traffic loading is noted as a 17-bit parallel digital interface.

2.4.2.2.3 ALCC traffic loading analysis for SCC-2. SCC-2 adds a tactical display capability to the operations center. This display is processor-driven from the TACC data sources. The interface between these units is provided through 17 parallel channels interconnecting the computer in the TACC with the display console in the ALCC. Tables 2-11 and 2-12 indicate the traffic requirements for the ALCC in SCC-2.

2.4.2.2.4 TUOC traffic loading analysis for SCC-2. The 485L program provides the TUOC with automated data storage and display and a digital information exchange between the TUOC and the TACC. The TUOC will exchange information with the DASC and CRC/CRP through the TACC communication links to these elements. The TUOC will be equipped with a remote data-source terminal and communications equipment to achieve the interface. Intrasite communications traffic for the TUOC is summarized in Tables 2-11 and 2-12.

2.4.2.2.5 ALCE/CCT traffic loading analysis for SCC-2. The configuration of the ALCE and CCT does not change in SCC-2.

2.4.2.2.6 CRC/CRP traffic loading analysis for SCC-2. The Army AN/TCC-69/70 radio is the primary addition to communication support equipment. Tables 2-11 and 2-12 summarize the CRC traffic flow for SCC-2.

As can be seen in these tables, there was very little impact on the traffic requirements of the switching system. This was due to our assumption that the new users introduced to the deployment replace the voice traffic which was transferred to the automated digital data links.

In addition to the shelters described in SCC-1, where it would be beneficial to know the flow of traffic integral to a shelter, only the MPC is of interest.

2.4.2.2.7 FACP traffic loading analysis for SCC-2. No changes were made to the FACP configuration for SCC-2 since the modification for upgrading the radar to the AN/TPS-43E was included in SCC-1. The traffic analysis remains the same as given in SCC-1.

2.4.2.2.8 ASRT traffic loading analysis for SCC-2. No change was made to the SCC-1 configuration or to the traffic flow for the SCC-2 ASRT.

2.4.2.2.9 DASC/TACP traffic loading analysis for SCC-2: The DASC configuration for the SCC-2 was modified only by the addition of a terminal 2400 b/s data in the operation center. In this configuration, as in SCC-1, it is assumed that each user is provided with an individual circuit to the AN/TTC-32 and a circuit to the nearest AN/TTC-30. The TACP configuration does not change for this concept.

2.4.2.3 System Configuration Concept No. 3. Concept SCC-3 addresses the use of TRI-TAC equipment in the TAF nodes. This configuration neither adds to nor deletes from traffic between nodes. Therefore, the traffic is identical to that for SCC-2, but the circuits required to service the traffic are changed.

The major impact of adding TRI-TAC equipment to the TAF nodal configuration is the type of traffic flowing between or within shelters. A minor impact is that of the TRI-TAC multiplex hierarchy or the circuit requirements.

For this configuration, it was assumed that the operations central shelters will not be replaced and the operators will continue to have access to the TA-720. It has further been assumed that the TA-720s will be used for communication between operating positions in the shelter. Each TA-720 will have one circuit to the AN/TTC-39. Each operating position will be provided with an applique unit housing a DSVT.

The DSVTs and data adapters that serve terminals in the operations central will access the switching centers, CNCE, or radio terminals as multiplexed loops. Loop group multiplexers will access these equipments with 17 active channels per unit.

User terminals that access the system from other than operations centrals may do so by either RLGMs, LGMs, or individual four-wire circuits. The analog-to-digital mix of these terminals will vary from node to node, but the basic rule used to define this mix was that 60 percent of the terminals were analog and 40 percent were digital.

A satellite system replaces the HF radio for long-haul interface circuits. It was assumed that all of the TTY and data circuits will remain dedicated back-to-back, and access the system via data adaptors.

2.4.2.3.1 AFCH/TACC traffic loading analysis for SCC-3. The AFCH/TACC configuration will change from that described in Figure 2-2. Major equipment additions are the SGT and CSCE, while other changes involve equipment substitution: The AN/TTC-39 automatic switch replaces the AN/TTC-30, the CNCE replaces the AN/TSC-62 tech control facility, and the AN/TCY-13 message switch replaces the AN/TGC-26 teletype relay center (which will automate the manual relaying of TTY traffic). Additionally, the AN/TRC-170 radio equipment will replace the AN/TRC-97A radio equipment for G/G communications.

Traffic analysis results for the AFCH/TACC in SCC-3 are shown in Tables 2-11 and 2-12. Since this configuration neither adds nor deletes traffic between nodes, the traffic is identical to that described for SCC-2. The major impact of the TRI-TAC equipment is the type of traffic flowing intrasite.

2.4.2.3.2 TWAC traffic loading analysis for SCC-3. SCC-3 incorporated the TRI-TAC equipments, converting the communications equipment to a mixture of analog and digital.

2.4.2.3.3 ALCC traffic loading analysis for SCC-3. The AN/TSQ-93 will be modified by replacing the AN/TTC-32 with a ULS 3865. Each console is provided with one DSVT for secure communications to the users.

In this configuration, the number of circuits between the ALCC and the AN/TTC-39 were reduced from two wire telephones to eight trunks (assuming 40 percent of the traffic terminates locally).

2.4.2.3.4 TUOC traffic loading for SCC-3: The communications interface traffic load remains the same for SCC-2 since the only impact was to add digital telephones to the TUOC for upgrading service quality.

2.4.2.3.5 ALCE/CCT traffic loading analysis for SCC-3. The configuration of the ALCE and CCT do not change from the SCC-1 organization and communications requirements.

2.4.2.3.6 CRC/CRP traffic loading analysis for SCC-3. SCC-3 consists of upgrading the equipment supporting the CRC with TRI-TAC developed communication equipment. Using these equipments, automatic interfaces to adjacent systems is provided. Replacement of the AN/TTC-30 with the AN/TTC-39 provides many features to allow the user to perform in a more efficient manner and have end-to-end security on a call-by-call basis.

Although the communication capabilities of CRC/CRP are enhanced by the introduction of TRI-TAC equipment into the node, the nodal configuration is identical to that of SCC-2. The TRI-TAC equipments introduced to the CRC include:

- A digital secure telephone (DSVT) at each operating position in the operations shelter;
- Replacing the AN/TSC-62 with the CNCE;
- Replacing the AN/TRC-97 with the AN/TRC-170;and
- Replacing the AN/TTC-39 with the AN/TTC-39.

It was assumed that each of the two TA-720 telephones would also share an analog circuit to the AN/TTC-39. This assumption is based on allowing the operator to continue using the TA-720 for nonsecure traffic in the customary operational manner.

There was no change in the TTY or data circuit requirements from SCC-2 to SCC-3, due to the assumption that these terminal devices would continue to operate at their present data rate, that the addition of TRI-TAC developed data adaptors would act only as a unit that interfaces low bit-rate devices to a high bit-rate line, and that the information rate on that line would continue to be that of the originating terminal. These data circuits were, therefore, routed to the AN/TYC-13 at the TACC in the same manner as the TTY circuits were routed to the AN/TGC-26.

Basically, there is no change in the traffic requirements from SCC-2 to SCC-3. But because of the modularity of the TRI-TAC digital multiplex family, the number of circuits required to carry this traffic is substantially increased. This increase can be seen in the following example:

a) In SCC-2, trunk group 1 uses 10 circuits to carry 4.8 erlangs of traffic. The trunk group modularity of the AN/TTC-39 is based on module 9. To carry 4.8 erlangs with at least a p=0.01 blocking requires two groups or 18 circuits.

b. AF route 2 in SCC-2 carries 11 dedicated channels, which requires two loop groups (18 channels).

The circuit and traffic requirements tabulation Table 2-12 for SCC-3 are based on the above constraints. The intrashelter requirement for handling radar information and processor information remains the same as that described in SCC-2.

2.4.2.3.7 FACP traffic loading analysis for SCC-3. The FACP was modified by SCC-3 to incorporate TRI-TAC elements. The AN/TSC-53 employs a modified CNCE patch panel, and CRF and CVSD A/D converters to fit internal to the shelter. The AN/TRC-170 replaces the AN/TRC-97A troposcatter radio.

The teletype-writer traffic was combined with interface traffic between the AN/TSC-53 and AN/TRC-170 to increase the erlang value by one.

2.4.2.3.8 ASRT traffic loading analysis for SCC-3. In this configuration, the MITRE phase-in plan added a ULS switchboard and suggested interface with a CNCE. Since the ASRT is collocated with the FACP, the ULS switchboard will interface via a landline with the CNCE equipment installed in the FACP.

An increase in the intrasite voice traffic is noted in this configuration since phones were installed in the AN/TPB-1 shelter and a switchboard is provided, reducing the necessity for shouting communications.

2.4.2.3.9 DASC/TACP traffic loading analysis for SCC-3. In SCC-3, the DASC is modified to include TRI-TAC developed equipments. The AN/TRC-97A is replaced by the unit-level switch SB-3865, and a minor node CNCE is incorporated into the AN/TSQ-93. Each operating position in the AN/TSQ-93 is also equipped with a DSVT. It is also assumed that the interface to the Army is now via a digital group multiplexer.

Tables 2-11 and 2-12 summarize the DASC traffic requirements for SCC-3. With the addition of the SB-3865, the 19.6 erlang traffic modified load was to 5.2 erlangs, i.e., an average of 0.2 erlangs per user terminal. Of this traffic, it was assumed that 75 percent is between the DASC and other TAC locations.

In this concept, the TACP will replace the AN/PRC-47 HF/SSB radio and AN/PRC-41 UHF radio with the AN/PRC-104 and AN/PRC-66B manpack radios, respectively, to provide secure voice capability. Additionally, the AN/UYA-7 data set will be installed in the AN/MRC-107 mobile communications center, and, its associated AN/TRC-146 radio will replace the installed AN/GRC-106 HF/SSB radio.

2.4.2.4 System Configuration Concept No. 4A. SCC-4A is an evolutionary step from SCC-3. It continues the use of TRA-TAC developed communications equipment and introduces new concepts for data distribution.

The number of cables and the signal transmission problems associated with deployed radars is minimized by digitalizing data at the radars and transmitting processed target information to consoles and computers via 16 kb/s data links. This allows any console at any location (now) to display any radar signal in the deployment.

All computer/processors at a node will be interconnected via a high-speed computer bus. Consoles that access these processors are also connected to the bus allowing any console at the node to access any processor. It also allows processor systems to share data bases.

In this concept, processors at adjacent nodes are interconnected via a data link. This allows the transfer of TADIL and DDL data at high bit rates between nodes, and facilitates processor-to-processor data transfers.

2.4.2.4.1 AFCH/TACC traffic loading analysis for SCC-4A. The AFCH/TACC configuration will change from that described for SCC-3. Major equipment additions in SCC-4A are the AFCH support processor and the TV receiver (E-3A). New and improved equipments will replace the following functional items:

- Operations central TACC;
- Data processing and display;
- Communications processor;
- Tropo/LOS radio; and
- JTIDS.

All processors and peripherals are assumed to be interconnected via a computer bus. The computer bus interface for this configuration is shown in Figure 2-2.

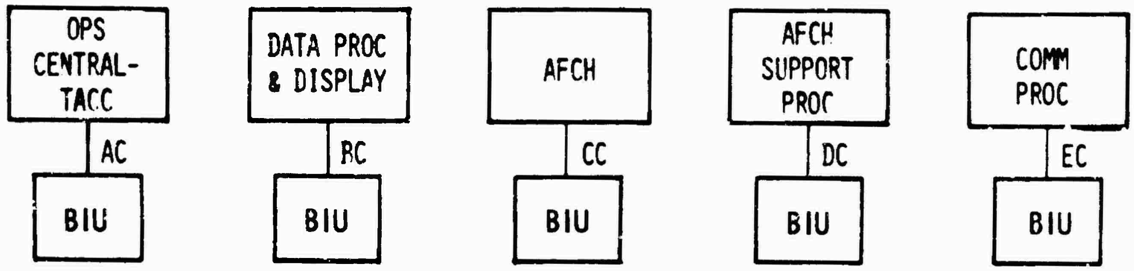
Traffic flow for SCC-4A is discussed relative to the traffic defined for SCC-3. These changes are described by means of changes to the traffic for SCC-3. These changes are reflected in Tables 2-11 and 2-12.

The major additions to the intershelter traffic are caused by the TV link and the processor-to-processor data links. The TV link requires a video circuit of 3.5 MHz at the AFCH. Intershelter traffic is increased to support intercenter high-speed processor-to-processor data links and a 16 kb/s FAX link to each TAB. Two 16 kb/s data links were assumed to connect each adjacent processor-equipped site.

The HF and UHF radio net traffic is assumed to be carried on the improved JTIDS system. The HF and UHF radios are retained for backup capability.

The addition of the computer bus changes connectivity between shelters from SCC-3 to SCC-4A. All computers and peripherals are assumed to be connected to this bus. These circuits replace the processor/processor/display connectivity in SCC-3.

With the addition of the computer bus in SCC-4A, both intershelter and intrashelter traffic can be carried on this bus. The processing and peripheral equipment contained in each shelter is shown in Figure 2-21. Data processing equipment in the same shelter can communicate with other DP equipment in that shelter by means of the computer bus.



	AC	BC	CC	DC	EC
CONSOLE/DISPLAY	20	2	8	2	2
CPU		2		2	2
DMA		4		4	4
DISC		10		10	2
MAG TAPE		4		6	2
PRINTER	1	1	1	2	1
PLOTTER		1		1	
PAPER TAPE					1

Figure 2-22. SCC-4A AFCH/TACC computer bus interface.

2.4.2.4.2 TWAC traffic loading analysis for SCC-4A. The basic configuration for the ALCC in SCC-4A is the same as that described for SCC-3 with one exception. The interconnect of the display module in the ALCC operations central to the TACC dispaly controller. This link is via the computer bus interface unit at the TACC. The traffic is listed in Tables 2-11 and 2-12.

2.4.2.4.3 TUOC traffic loading analysis for SCC-4A. No change was made to the TUOC system organization in the transition from SCC-3 to SCC-4A.

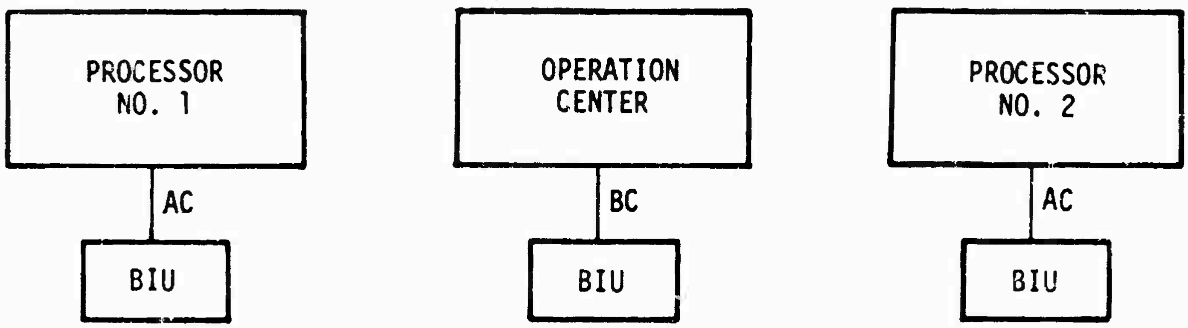
2.4.2.4.4 ALCE/CCT traffic loading analysis for SCC-4A. In SCC-4A, the HF, UHF, and VHF networks have been replaced by an advanced JTIDS system providing access not only to the networks indicated but also interfaces to the bus system located at other TAC sites. Remote terminal operation using processors at the TACC and access to the circuit and packet switch systems is provided via this link. A local intraconnect unit is also provided as a backup to this system. This allows the ALCE to access the bus system at a TAB.

Traffic volume for the ALCE and CCT are assumed to remain approximately as estimated for SCC-1.

2.4.2.4.5 CRC/CRP traffic loading analysis for SCC-4A. The basic capabilities of the CRC/CRP are enhanced by provisions for a data link between processors at adjacent nodes, (e.g., CRC, CRPs, and TAC); interconnecting all of the processors at a node; via a bus system providing display consoles direct access to that bus system; interconnecting the radard to the processing system with a 16 kb/s digital link; and using an advanced JTIDS to support the HG, VHF, and UHF network requirements. The UHF and HF equipments are retained as backup.

The traffic requirements for SCC-4A are listed in Tables 2-11 and 2-12. The major impact shown in this table is due to the transmission of the radar video signals via a single 16 kb/s data link. Addition of the computer bus requires that traffic for this bus be defined separately from that shown in the Table.

Figure 2-23 depicts the computer bus concept and indicates location and numbers and types of equipments to be served by the bus. The following paragraphs discuss the traffic requirements for the bus.



<u>AC</u>

1 CPU
4 MAG TAPES
3 DATA CHANNELS
1 TAPE READER
1 TAPE PUNCH
2 DISPLAY CONSOLES
1 KEYBOARD/PRINTER
1 DIRECT MEMORY ACCESS
1 DISC

<u>BC</u>

12 DISPLAY CONSOLES
2 PLOTTERS

Figure 2-23. SCC-4A CRC computer bus requirements.

Intrashelter information flow was estimated for the maximum-configuration CRC employing a three-cell AN/TSQ-91 operations central collocated with an AN/TYC-10 MPC. A block diagram of the intrashelter intraconnect is shown in Figure 2-24. An interface unit has been added to the CRC for DCR returns which replace the video signals previously sent from the AN/TPS-43 radar. When the DCR concept is developed, it is expected to consolidate many of the video signals in the CRC and provide a digital transfer of much of the information previously handled by video control units. Quantification of intrashelter traffic for each major equipment item is described below.

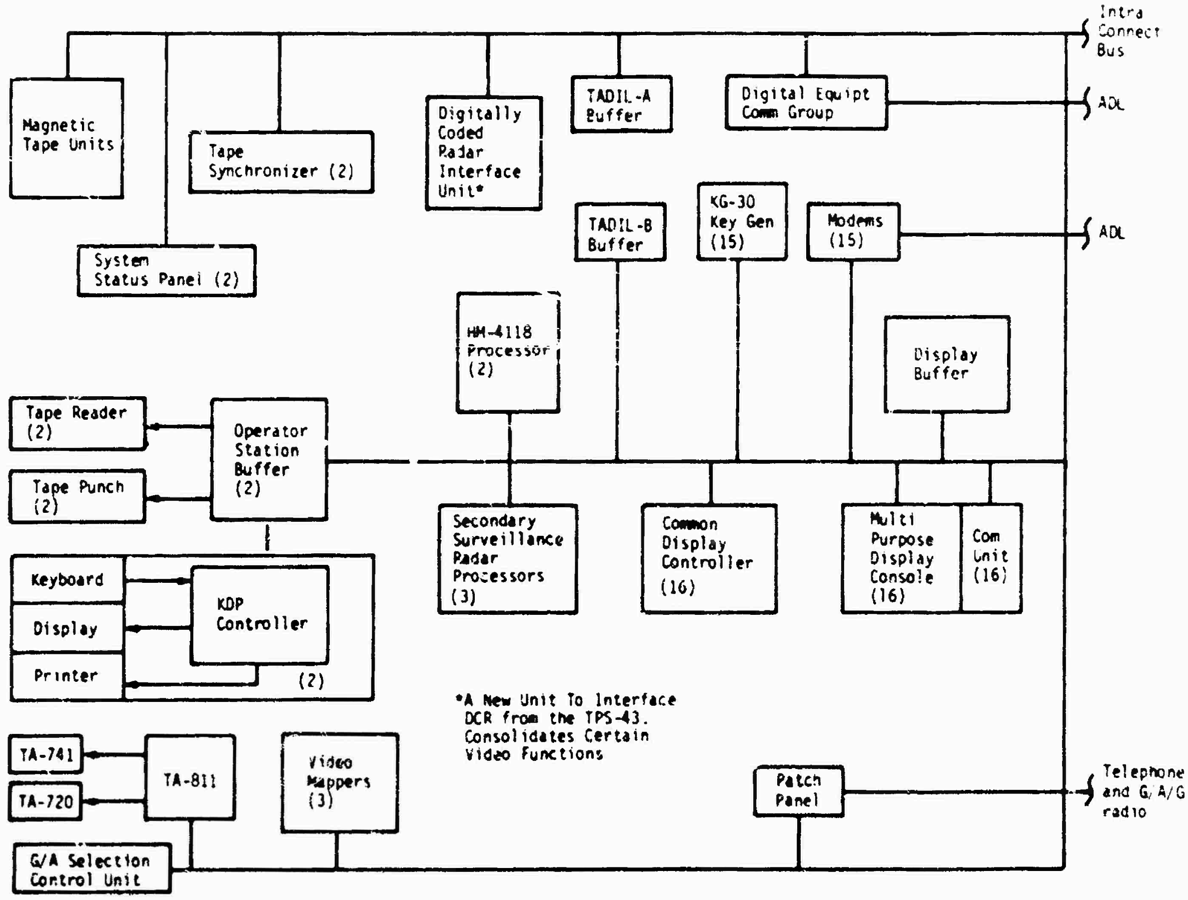


Figure 2-24. CRC maximum configuration intrashelter bus, AN/TSQ-91 and AN/TYC-10 collocated with three operational cells.

Data Processing - The HM-4118 is a general-purpose binary, parallel computer with an 18-bit word length and a core memory of 131,072 18-bit words. The main features of the computer are its 4 MHz clock rate and its coincident-current, random-access memory with a cycle time of 1 μsec. The maximum data transfer rate over any one of its width channels is 500,000 words/second (w/s). When two or more channels are operating, the maximum data rate increases to 1,000,000 w/s or 18 Mb/s (18-bit words). In the MPC, the output channels are assigned as follows:

- System status panel;
- Common display controller (multipurpose consoles);
- Magnetic tape synchronizer (magnetic tape units);
- Operating stations buffer (keyboard, display, pronter paper tape punch, and paper tape reader);
- TADIL-B Buffer (TADIL-B/Link 1 automatic data link); and
- TADIL-A Buffer (TADIL-A automatic data link).

Similarly, the processor in the AN/TSQ-91 addresses its output channels, which are the same, but includes a display buffer and correlation buffer and not the TADIL-A port. Its maximum aggregate output is also 18 Mb/s.

DCR interface unit - Data will be transferred from the radar to the CRC DCR interface unit over the intershelter bus at a rate not to exceed 16 kb/s. The 16 kb/s transfer rate is taken as the maximum for all data that were previously transmitted as video, i.e., height bits, video, and trigger signals between the SSRP, video mappers, and DCR. The three video mappers, three SSRPs and DCR constitute seven such channels requiring 112 kb/s.

Common Display Controllers (CDC) - The information transfer rate between the PPI and ARO symbol generators and between the display buffer (in the AEM) and the console modules, is at the display clock rate of 1.67 Mb/s. The serial data from the PPI symbol generator and display buffer are in the form of 24-bit words with three clock periods between each word, while the serial data from the ARO symbol generator is in the form of 18-bit words with three clock periods between each word. This is the transfer rate of data to the common display controllers. The aggregate of this transfer between display buffers, 16 CDCs, and 16 display consoles is as follows:

Display buffer	19.20 Mb/s
CDC	26.72 Mb/s
Displays	5.76 Mb/s

Telephone and radio communications - The telephones in the CRC are serviced by 72 lines including internal lines and those connecting externally to the switch and to A/G radios. The phones are digital and operate at 32 kb/s. The total traffic requirement for these lines is 1.120 Mb/s.

Automatic Data Link (ADL) - The ADL includes all digital communication traffic interconnecting the CRC with external links. The requirements for these links are:

8 TADIL-A at 2250 b/s maximum	18 kb/s
20 TADIL-B at 2400 b/s maximum	48 kb/s
2 Link 1 at 1200 b/s maximum	2.4 kb/s
	68.4 kb/s

Total intraconnect traffic load - The total traffic load requirement of a maximum-configuration CRC (including MPC) on the intrashelter intraconnect is 88.978 Mb/s.

2.4.2.4.6 FACP traffic loading analysis for SCC-4A. In SCC-4A, the main impact on the FACP is from remoting the AN/TPS-43E radar signals. This requires modification to digitize the radar target information, a remote control interface, and a data and voice multiplexer.

In this concept, the control data from the AN/TSQ-61 is transmitted at 16 kb/s to the remote control unit at the surveillance radar and the IFF interrogation. The positional information and identity from the radar system is digitized and transmitted to the display consoles in the AN/TSQ-61. Two voice channels are provided to interface with the switchboard in the AN/TSC-53. A traffic summary is shown in Tables 2-11 and 2-12.

2.4.2.4.7 ASRT traffic loading analysis for SCC-4A. The ASRT is no longer dependent on the FACP to provide the communiations link to the CRC. JTIDS is used to communicate with the TAF elements, including mission aircraft. Table 2-11 summarizes the traffic flow.

2.4.2.4.8 DASC/TACP traffic loading analysis for SCC-4A. In this concept, the hardware remains basically the same as that described for SCC-3. JTIDS will carry the traffic previously carried on the UHF, VHF, and HF radio networks. Tables 2-11 and 2-12 summarize the traffic.

The TACP interfaces the advanced JTIDS communications net. The HF/UHF radios supporting the voice and data network will be replaced by the advanced JTIDS terminal.

2.4.2.5 System Configuration Concept No. 4B. SCC-4B retains the features developed in SCC-4A of intercenter computer links, intracenter computer buses with distributed processing, and remoted digitally coded radios. It introduces the concept of networks of distributed medium-range radios, radios and networks of sensors, and the integration of circuit switching and transmission group reassignment functions to the intraconnect.

The networks of radios, radars, and sensors will require additional communication links for coordination and control, which adds to total traffic loads. Such functions will be performed for the most part over digital data links at rates not expected to exceed 16 kb/s per channel.

While the integration of the switching functions with the intraconnect bus will not affect total traffic, it will reduce significantly the load the intraconnect must carry by eliminating traffic duplication at access and egress points of both circuit switch (AN/TTC-39) and technical control element (CNCE) in previous concepts.

2.4.2.5.1 AFCH/TACC traffic loading analysis for SCC-4B. SCC-4B is an evolutionary system derived from SCC-3 and -4A. All intershelter traffic is routed through a communications control center that performs the functions of circuit and message switching, technical control, and bus control.

Two 16 kb/s data links are provided to each adjacent processor-equipped site.

Traffic flow for SCC-4B is discussed relative to traffic for SCC-4A. These changes are described by means of changes to the traffic for SCC-4A.

The intershelter traffic for this configuration is basically the same as for SCC-4A; however, the connectivity of the functional entities is different.

The TACC operations central, AFCH, and support units are provided with digital telephones in the same quantities as required in SCC-1 and -2. No changes were made from SCC-4A in the estimated traffic in erlangs for the switched voice traffic.

2.4.2.5.2 TWAC traffic loading analysis for SCC-4B. In this configuration, the major changes occur in the communications interface at the TACC. Equipments in the TWAC that now interface with a communications control module are digital and operate at a standard 16 kb/s rate. The TDU/MEDU is modified to operate at 16 kb/s serial data-transfer rates.

While the traffic volume did not reflect an increase, the interface with the network did increase in bit rate since all ground communications are assumed to be digital. The bit rates of the HF and satellite FAX will likely remain low since the HF is a remote operation backup and the satellite is bandwidth-limited. If data from these sources are inserted into the communications control center bus, then the bit rate will be increased to 16 kb/s by multisampling.

The weather radar must maintain a high-resolution signal to the display. Therefore, the 6 MHz video must be treated as an analog input. Table 2-11 summarizes the traffic load on the TWAC.

2.4.2.5.3 ALCC traffic loading analysis for SCC-4B. In this system concept, the operations central is connected directly to the bus systems associated with the communications control center serving the TACC. ALCC is entered in Tables 2-11 and 2-12. Here, the TTY traffic is handled by the packet switching system, which is an integral part of the communications central. It was also assumed that the traffic presently carried via the AN/UYA-7 would be replaced by two 16 kb/s circuits JTIDS.

2.4.2.5.4 TUOC traffic loading analysis for SCC-4B. In this configuration, the TUOC is converted to digital communications, operating at 16 kb/s. The display interface is converted to 16 kb/s serial data transfer. A high-speed printer interface is provided to down-convert the printer bit from the 16 kb/s input. A radio is shown (AN/PRC-153) for reference only. The interface to the aircraft will most likely be via the JTIDS. Tables 2-11 and 2-12 summarizes the traffic load for this concept.

2.4.2.5.5 ALCE/CCT traffic loading analysis for SCC-4B. The organization and traffic loading for the ALCE and CCR are assumed to remain as described for SCC-4A.

2.4.2.5.6 CRC/CRP traffic loading analysis for SCC-4B. The nodal configuration for SCC-4B is a dramatic change from that described for previous SCCs. All equipments at the node are served by the communications control module. In addition, the single radar used in all previous concepts has been replaced by a netted radar concept. Each radar digitizes its output and transmits the data back to the CRC via a 16 kb/s link. Although the figures indicate radars are all located at the CRC and the traffic analysis indicates 16 such units, these units may be located anywhere in the deployment and their signals transmitted to the CRC via standard 16 kb/s communication links.

For this scenario, we have also assumed that each console in the system can be served by 32 kb/s channels for displays, access to communication capabilities, and common-user services. The capabilities of the node have been enhanced by using of a bus system that interconnects all user devices to all support equipments.

The communication support package includes both circuit-switch and packet-switch capabilities.

Tables 2-11 and 2-12 list the traffic and circuit requirements for SCC-4B. Evaluating the requirements against that in SCC-4A, traffic flowing around a node has been substantially decreased. The reasons for this reduction are the assumptions that circuit switching is accomplished on the bus and that packet switching is employed for transmission of much of the data.

2.4.2.5.7 FACP/FARS traffic loading analysis for SCC-4B. SCC-4B, a , new medium-range FARS is employed to interface with the CRC/CRP through JTIDS. As noted in Tables 2-11 and 2-12, the number of circuits is reduced, since a part of the FACP functions are now controlled from a remoted position (i.e., CRC). The communications interface is via an improved JTIDS using two 16 kb/s, full-duplex channels. Target-track information and control data occupy one 16 kb/s channel.

2.4.2.5.8 ASRT traffic loading analysis for SCC-4B. SCC-4A and 4B are considered identical. Traffic loading for the ASRT in SCC-4B is the same as for SCC-4A.

2.4.2.5. DASC/TACP traffic loading analysis for SCC-4B. In this concept, the equipment is interconnected via a bus system at the communications control center. All equipment in the shelters will individually access the bus. The bus system acts as the technical control and switching center for the node. Tables 2-11 and 2-12 summarize the traffic requirements on the bus.

2.5 Performance requirements.

Intraconnect design must be compatible with an evolutionary time-phased growth of C^3 equipments as shown in SCC-1 through SCC-4B. In the initial application of the intraconnect, it is assumed that technical control (AN/TSC-62 or AN/TSQ-111) and circuit switch (AN/TTC-30, AN/TTC-39, AN/TTC-42, or SB-3865) will exist in the C^3 centers. But the post-TRI-TAC era (SCC-4B) it is expected the next generation of switching, technical control, and communications call processing equipment will be integrated to some degree into the intraconnect system on a distributed basis. Therefore, the intraconnect design must provide the inherent ability to evolve without major cost or redesign, from the early SCCs, through the SCC-4B period.

A modular design approach is needed to facilitate growth without obsolescence and the adaptation of the intraconnect to both samll centers, such as the FACP and DASC, and large centers, such as the CRC and TACC.

Since the primary challenge is to satisfy the operational requirements of the larger centers, the TACC and the CRC (Figures 2-25 and 2-26) were selected as a basis for the architectural analysis. Aside from the presence of the search radar in the CRC, but not in the TACC, the two systems are similar in communications layout. The communications traffic load of the TACC is higher than that for the CRC. The ADP traffic load is higher in the CRC than in the TACC. The link numbers in the Figures refer to the quantity of wire pairs available between system elements using the present 26-pair cables for the intraconnect.

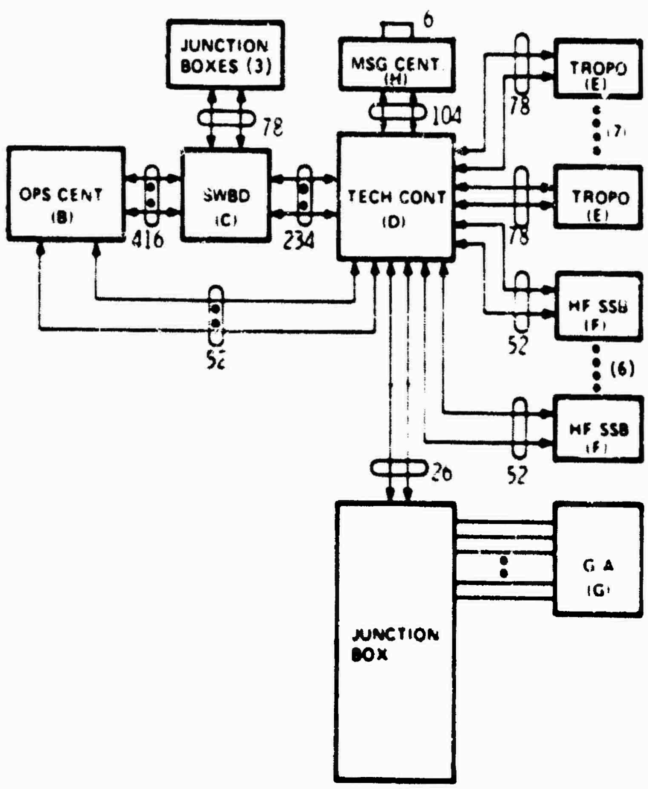


Figure 2-25. Typical communications intense facility (modeled on maximum CRC).

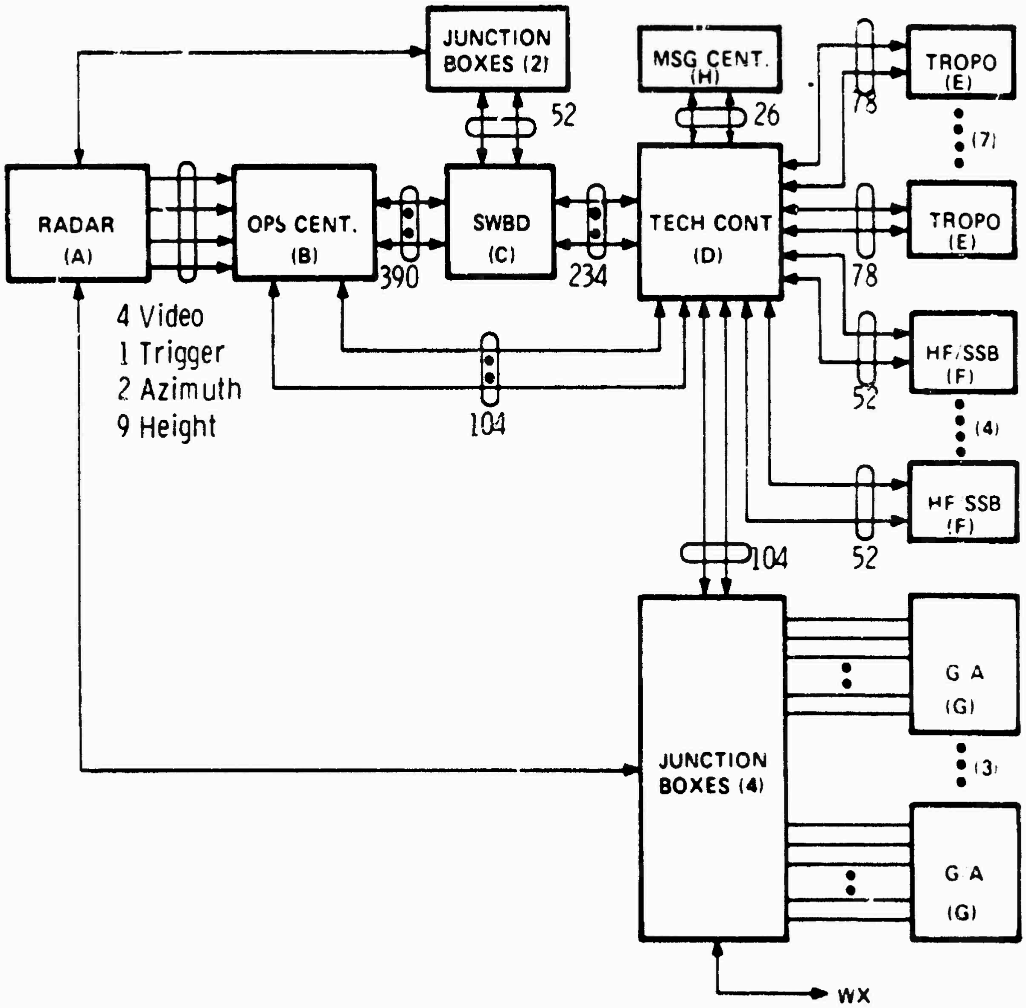


Figure 2-26. Typical intense facility (modeled on maximum CRC).

Because of the similarity between the maximum CRC and the TACC, the design technique and concept candidate tradeoffs were based upon an intraconnect model for a CRC/CRP with the communications traffic load (in both number of circuits and erlangs of traffic) increased to equal that of a TACC. This provides a large-center model representative of the worst case, including radar link.

The information flow studies identified three major categories of traffic that must be carried by the intraconnect for this model. They are:

a. Radar information, characterized by wideband analog video data:
   1. IFF/SIF composite video at 6.0 MHz bandwidth;
   2. MTI gated and search video, each at 4.0 MHz bandwidth;
   3. Pretrigger and nine height signals, each at 1.2 MHz bandwidth; and
   4. Synthetic video, azimuth change pulses, and north mark; each at 0.6 MHz bandwidth;

b. Communications information, characterized by narrowband analog or serial digital data:
   1) Voice/facsimile, either 4 kHz analog or 16/32 kb/s digital data;
   2) Automatic data link - low-speed serial, digital data - generally between 150 and 4000 b/s; and
   3) Teletypewriter - low-speed, asynchronous, serial, digital data - generally between 35 and 2400 b/s.

c. ADP information, characterized by wideband, generally bit-parallel-word serial, digital data at rates varying from less than 100,000 words/second to the 1,000,000 words/second range, with word lengths (bus widths) of from 8 to 36 bits:
   1) Processor-to-processor, offering relatively high-speed, parallel transfer of data between two or more processors handling different functions or load sharing a single large function.
   2) Processor-to/from-peripheral(s), offering high-speed parallel transfer of program (during program paging or overlay operations) or data base (for access of either a common data base by several processors or for access by one processor of another processor's data base in distributed processor, load sharing, or backup modes); and also between processors and operator consoles in future systems.
   3) Peripheral-to-peripheral, an anticipated mode whereby operator consoles could directly interchange data while conferencing.

A traffic summary for this model is included in Table 2-11 and 2-12 of subsection 2.4. Note that the bit rate capacity requirements for both the intershelter and intrashelter buses are approximately 150 Mb/s. The tables also indicates the allocation of this capacity to communication traffic, ADP traffic, and overhead data for intraconnect signalling and control functions.

3.0 SYSTEM DESIGN

This section describes results of studies performed to investigate the various techniques and concepts in the design selection. The recommended concept is described and the rationale presented to support the choice of techniques. With few exceptions, tradeoffs and choice of design techniques were clearly evident after detail analyses of performance and cost.

Subsection 3.1 identifies the most promising alternative techniques considered and summarizes the conclusions regarding each of these alternatives. Subsection 3.2 describes the recommended concept.

3.1 Architecture trade-offs.

A wide range of techniques were considered in defining the concept candidates. Alternatives were identified in network topology, control/protocol, multiplexing, and transmission media. These alternatives are discussed below, with the rationale guiding selections in each case.

3.1.1 Alternative intraconnect topologies. Three basic network configurations were considered for the intraconnect links between shelters and between devices within a common shelter. They are as follows:

a. Conventional open-loop bus layout. A single-bus transmission path that winds through the site, passing by each element of the C^3 system. Each element connects to the bus by a T-tap at its nearest approach. A closed-loop configuration of this approach was also considered.

b. Inactive star layout. Multiple interconnects between the interior (closely grouped) system elements and a single, direct interconnect between the technical control (AN/TSC-62 or AN/TSQ-111) and each of the radio equipments in a star arrangement. The radar, where present, would connect directly to the using element. This is the topology of the present intraconnect for the C^3 centers.

c. Active star layout. A central transponder (T) controller which has a single direct interconnect to each element of the system. Elements in separate shelters communicate with each other through the transponder.

3.1.2 Alternative intraconnect control/protocol techniques. Several methods of controlling access to an intershelter and intrashelter were considered:

a. Centralized static circuit switch. A computer-controlled switch matrix/patchboard providing a fixed set of connections among subscribers that are usually fixed (dedicated) to an operating center requirement and altered only at times of system reconfiguration (analogous to a computer-controlled technical control function such as the AN/TSQ-111).

b. Centralized dynamic-circuit switch. A computer-controlled switch matrix providing call processing functions and call-by-call connections on demand (analogous to a standard telephone switchboard/central office such as the AN/TTC-30, AN/TTC-39, AN/TTC-42 and SB-3865).

c. Integrated bus, switch, and technical control. A concept wherein many of the switching functions normally done by a circuit switch and technical control facility are integrated with the bus. The bus, a pocket switch, duplicates the switching matrix of the circuit switch and in the channel reassignment function of the technical control facility.

d. Contention/request bus control. Control in which subscribers contend for bus access by transmitting a separate request. Contentions are resolved by scanning all request lines in priority sequence.

e. Static dedicated slot bus control. Control where in bus time is divided into numerous specific time slots, each one dedicated to the use of a specific subscriber on a fixed basis, generally altered only at times of system reconfiguration.

f. Dynamic dedicated slot bus control. Here, bus time is again divided into numerous specific time slots, each of which can be assigned to any subscriber for the duration of a communcation on a demand/priority/precedence basis.

g. Polled bus control. Control wherein subscribers transmit only when they are polled, via the bus by a bus control unit.

h. Loaned bus control. Control wherein subscribers act as in polled control but polling and supervision are carried on a separate channel from data (outside the bus proper).

3.1.3 Alternative multiplexing techniques. Four methods of carrying multiple communication channels on a command intershelter or intrashelter were considered:

a. FDM/FDM/FDM. The standard FDM technique of building groups by frequency stacking voice (4 kHz) channels, frequency stacking the groups into supergroups, and finally stacking supergroups into mastergroups.

b. TDM/FDM/FDM. An analog-to-digital (A/D) method for converting basic-voice (4 kHz) channels into CVSD digital (16/32 kb/s) channels, forming initial low-speed groups by TDM of several channels, frequency stacking the groups into supergroups and then into mastergroups.

c. TDM/TDM/TDM. A/D converting channels as in TDM/FDM/FDM and TDM/TDM/TDM above, forming groups and supergroups by hierarchical time-division multiplexing as in TDM/TDM/TDM above, then sending the several supergroups via separate, space division multiplex (SDM) paths, e.g., separate fibers in a multifiber optical cable.

3.1.4 Alternative Transmission Media. Three basic types of transmission media were considered for this intershelter bus:

a. Cable television. A medium characterized by a single coaxial cable distribution system using system components available from a CATV industry. Generally, either a 5-300 MHz simplex bus or a 5-110/170-300 MHz full-duplex bus is used.

b. Fiber optics. A medium characterized by either a light-emitting diode (LED) or semiconductor laser source, glass (silica) or plastic fiber conductor, and a positive-intrinsic-negative (PIN) diode or avalanche-photo diode (APD) detector. Bit rates up to 100 Mb/s are currently possible, with higher bit rates anticipated as technology matures.

c. Electromagnetic radiation (EMR). A medium considered in three distinct bands:

1. Radio - up to 1 GHz;
2. Microwave - from 1 to 30 GHz; and
3. Millimeter wave (mmw) - above 30 GHz generally but, more specifically for the purposes of this analysis, the 5 mm band from 57 to 63 GHz where absorption by atmospheric oxygen exceeds 10 dB/km at any altitude up to 3 km.

Cable Television, fiber optics, and multiconductor ribbon cable were considered for the intrashelter bus transmission media.

3.1.5 FI candidate systems. The alternative design candidates from 3.1.1 were included in five most promising systems. These systems were then evaluated in a trade-off to determine which systems was best for FI applications. These candidate systems are:

- Millimeter wave-frequency division multiplex (mmw-FDM);
- Millimeter wave-time division multiplex (mmw-TDM);
- Cable television-frequency division multiplex (CATV-FDM);
- CATV-TDM Cable television-time division multiplex (CATV-TDM);
- Fiber optics-time division multiplex (FO-TDM).

3.1.6 Evaluation methodology. The cost-effectiveness methodology developed to aid in the concept selection process was based on previous experience in performing similar evaluations during the Army Integrated Tactical Communications System (INTACS) study. Recommendations for the selected intraconnect concept are based on evaluations of cost and operational effectiveness for candidate concepts that meet TAF requirements. The maximum configuration for the CRC was chosen as a basis for the evaluation.

The intraconnect architecture analysis performed in Task I defines the candidate protocol/transmission technologies and candidate concepts best suited for producing a flexible, modular, composite system capable of serving TAF facilities in future SCCs.

3.1.7 Selection of most cost-effective candidate. The fiber optics transmission system is selected for the most cost-effective candidate. The demand-access polled-bus control scheme is chosen over the contention approach for its simpler crypto requirements and for its ability to handle mulitple levels of precedence. Its cost is higher than the contention approach in SCC-4A (by $24,000 for equipment only) but lower in SCC-4B (by $33,000 for equipment where the cheaper LIUs offset the more expensive subscanners). The life-cycle cost difference ranges from 1.6 percent to 3.2 percent depending on concept and implementation.

The star bus configuration with an active transponder and bus control unit is retained and augmented with a second-level bus within the shelter that has a submaster controller called an LICU permitting users of the sub-bus to communicate independently of the star bus and to do this even in the case of link loss to the transponder.

Although performance and cost comparisons were based on a maximum link length of 1500 feet (0.5 km) (the capability of the current system), there is no inherent constraint precluding greater separation between units. The fiber optics and millimeter wave candidates are both capable of 8 km range with lower signal margins but still within the performance specifications required. The CATV candidate accommodates cable runs longer than 1500 feet with a cable repeater for every additional 1500 feet at a per-unit cost of $650. This would reduce the availability of the CATV system as a result of the additional 425-foot reels of cable and the repeaters. Availability of the fiber optic and millimeter wave radio candidates would not change if separation between the transponder and other shelters were increased to 8 km. There would be no change in the radio equipment (although outages from propagation anomalies might be more frequent and longer lasting) and 8 km fiber optics cables can be driven with the specified T/R units as well as 0.5 km cables. The fiber optic cables would be configured on one-piece, 1 km cables weighing about 70 pounds (32 kg) and required a two-man cable-laying crew. This would increase the installation time for a fixed crew size beyond the additional walking time involved.

3.1.8 Summary and conclusions. Fiber optics transmission have the most cost-effective performance in all four system configuration concepts. Salient advantages and comparisons with the current cable system are presented in Table 3-1. With a 10-year life-cycle cost at 1978 prices (including manpower costs for technical control and switch operators) of less than 2/3 the present cable system, it has other advantages including greater bandwidth potential; resistance to degradation from EMP, RFI, or lightning; and lower service outages (less than 1/18 the cable system for the two-link case).

TABLE 3-1. FIBER OPTIC BUS ADVANTAGES AND COMPARISON WITH PRESENT SYSTEM

ADVANTAGE	FIBER OPTIC PERFORMANCE	CURRENT SYSTEM
Fastest service restoration	One-half hour per link	Two hours per link
Cable impervious to EMP or lightning disruption	Nonmetallic glass fiber; bit error rate $\approx 10^{-8}$	Worst - 52 metallic conductors per cable carry bulk current induced of 10,000 amperes*
Two link availability best	0.9974 or better	0.9524 availability; unavailability is 18.3 times that of fiber optics
Smallest size, lowest weight	94.8 cu ft; 1863 lbs (SCC-1, -2, and -3)	Heaviest, biggest (18,240 lbs, 534 cu ft)
Lowest cost alternative now, with further cost reductions in prospect	$6.9M (SCC-1, -2, and -3)	Most expensive alternative ($10.8M LCC)
Available bandwidth adapts easily to service expansion	100 Mb/s per fiber, 7 fibers available per link	4 kHz bandwidth per pair; could carry 1.544 Mb/s per pair with T-carrier equipment

*J.E. Godts, "Lightning Probability Damage and Hardening Requirements," 1977 IEEE International Symposium on Electromagnetic Compatibility Conference Record, August 1977. (For WM-130 which is used in CX-4566 cable.)

Rapid improvement in fiber optics technology and sharp reductions in component costs are expected as a result of increasing acceptance of this transmission medium for other applications in telecommunications, industry, and the military.

A static, dedicated time-slot bus architecture was found to be effective in SCC-1, -2, and -3, but this is upgraded through an evolutionary approach leading ultimately to an adaptive demand-access bus providing rapid access and multiple levels of message precedence.

Costs for R&D were charged against the candidate SCC in which they first appeared, assuming an evolutionary approach. It is possible, however, to start with an advanced concept and calculate the life-cycle cost for it (assuming no prior developments) by adding in the R&D costs for components for which R&D was expensed in an earlier SCC. All cost data are presented in Appendixes I and J of Task I Final Report, allowing the reader to cost his own system combinations.

3.2 Recommended architecture.

Recommended system architecture is a two-level bus concept using an active star topology for the intershelter bus (Figure 3-1) and an open-loop conventional bus topology, (Figure 3-2) for the intrashelter bus. The bus access protocol consists of a two-level polling scheme allowing a great flexibility in bus access during the evolution from the SCC-1 through SCC-4B configurations. In SCC-1, -2, and -3, a simple fixed-sequence, polled approach is used for intershelter bus access while a separate fixed-sequence, polled approach is used for intrashelter bus access. In SCC-4A and -4B the polling algorithms will be changed to a demand-access technique in both the intershelter and intrashelter buses to provide dynamic bus access.

The versatility of the protocol design permits compatible operation between the intraconnect and the interfacing C^3 equipment during each stage of its evolution. As more sophisticated ADP and switching equipments are phased into inventory, the operational capabilities of the intraconnect are upgraded to complement these concepts without reengineering the intraconnect.

3.2.1 Intershelter bus. The intershelter bus transmission system consists of two links between the transponder and each shelter: One up-link from the shelter to the transponder, and one down-link from the transponder to the shelter. The first level of polling for transmission of data between shelters is performed by the transponder/controller, which polls one shelter at a time in the specific sequence defined by the polling algorithm. This is accomplished by transmitting all the polled shelter's polling data, including its address over every down-link in the STAR.

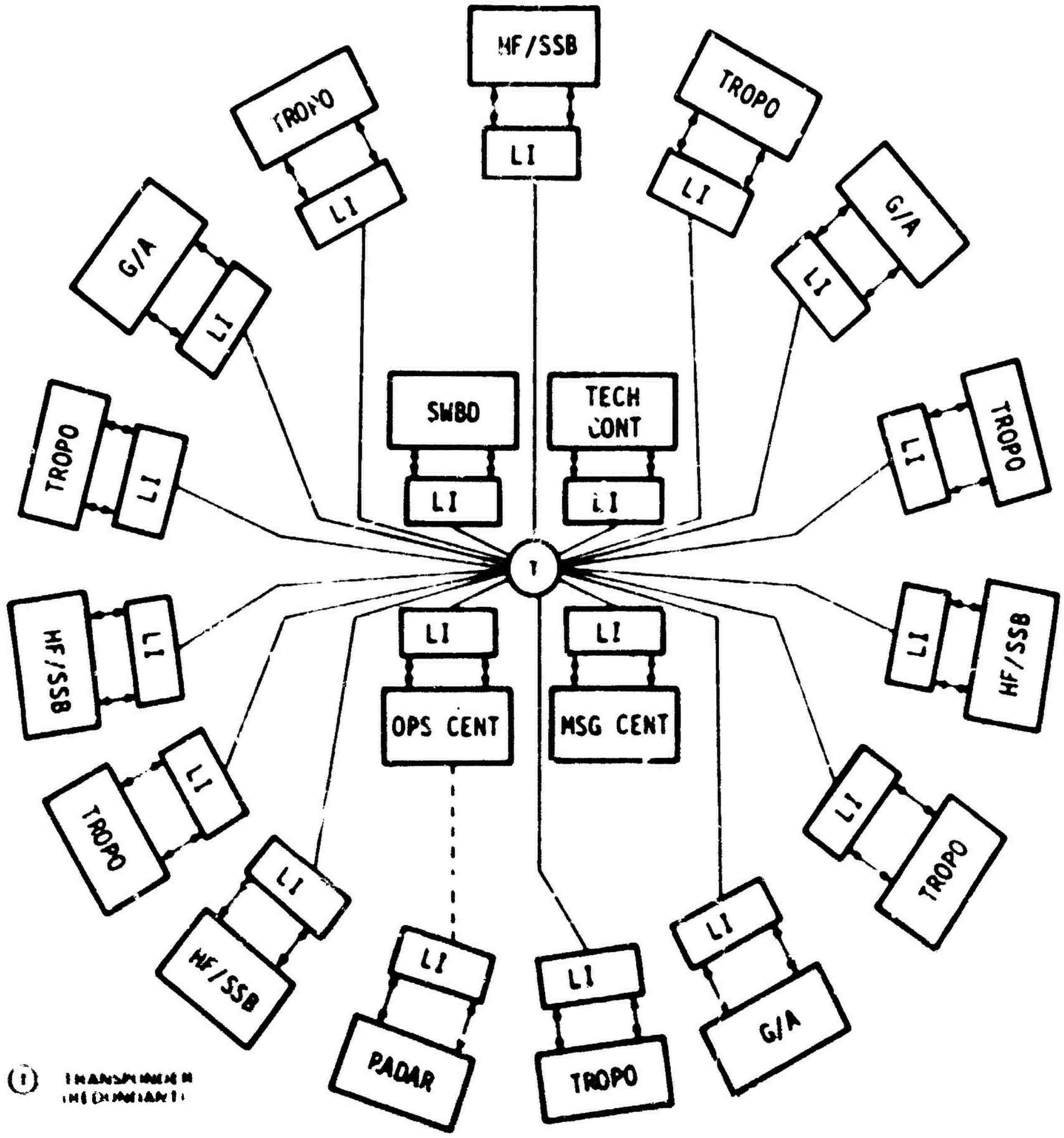


Figure 3-1. External intraconnect topology.

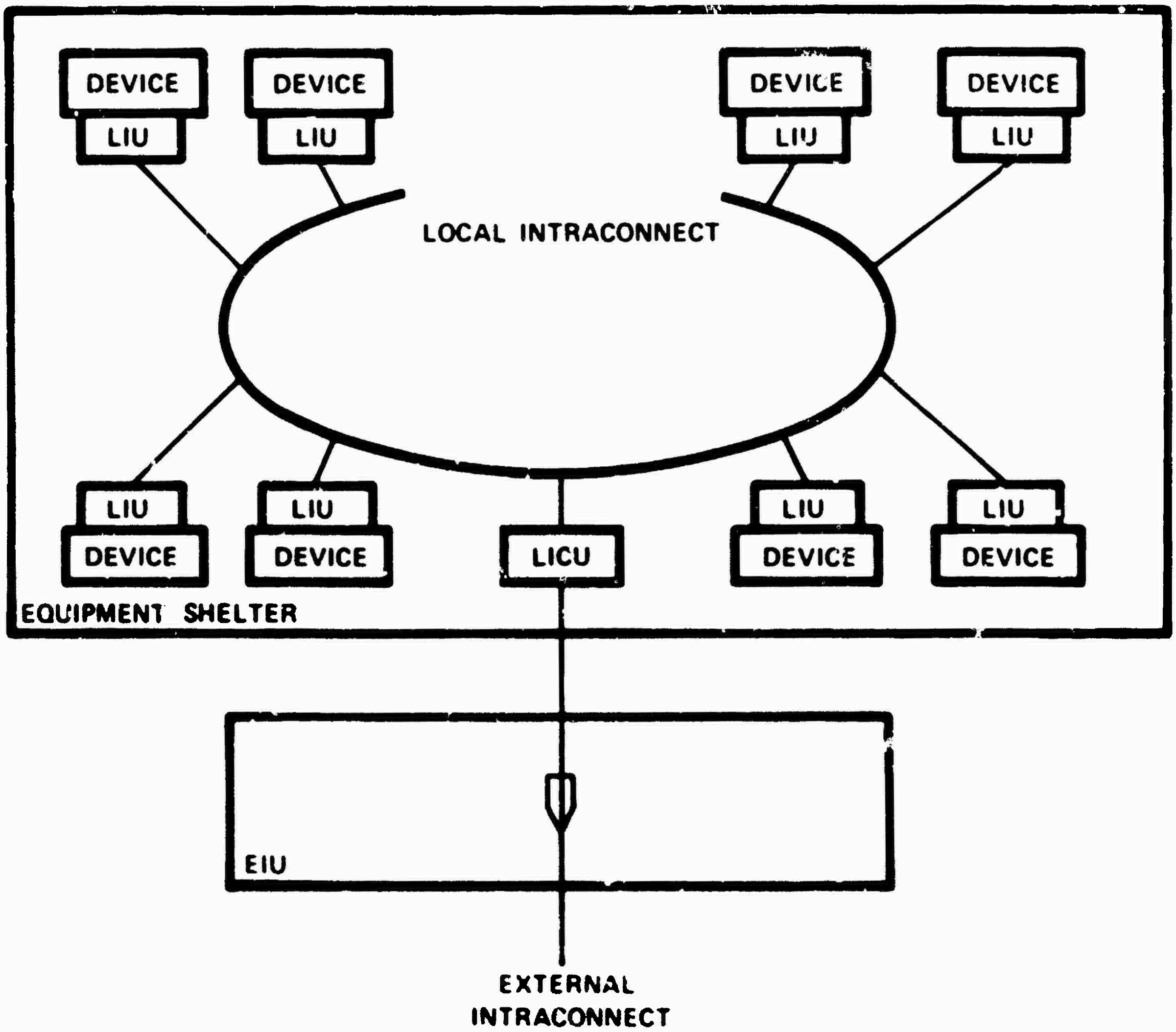


Figure 3-2. Local intraconnect topology.

Upon recognition of its address and polling information, the polled shelter then transmits its response over the up-link to the transponder. This response includes the status of the polled shelter plus all data from its subscriber terminals that are to be transmitted to other shelters. The transponser retransmits the shelter's response over the inter-shelter down-links to every shelter in the system. Each shelter receives all transmissions on the bus from all sources. However, a shelter responds only to those transmissions addressed to it and to its subscriber terminals.

The polling mechanism in the External Intraconnect Control Unit (EICU) is designed so the intrashelter polling algorithm is operator-selectable from a simple fixed-sequence polling scheme to accommodate the static-polling nature of the bus in SCC-1, -2, and -3, to a sophisticated priority-polling algorithm scheme on a dynamic basis in SCC-4B.

Intershelter bus signals are multiplexed in a TDM/TDM/TDM hierarchy and transmitted between each equipment shelter or assemblage of shelters and the transponder, via a multi-fiber optical cable. Four fibers carry 50 Mb/s data each, and one fiber carries clock, and high-speed video channels. At each shelter, an external intraconnect (EIU) interfaces the external bus to that shelter. Each EIU consists of five LED and APD transceivers along with four 10:1 multiplexer/demultiplexers arranged as shown in Figure 3-3. Each EIU, therefore, provides the interface between the intershelter bus' fiber optic transmission media outside the shelter and its electrical transmission media within the shelter. It further converts the four high-speed (50 Mb/s) channels to a set of 40 parallel 5-bus channels. Thirty-six of these channels are used as the data bus; the remaining four channels for 5 MHz clock and three control lines. The same optical transceiver and multiplex circuitry is used at the other end of the link in the transponder.

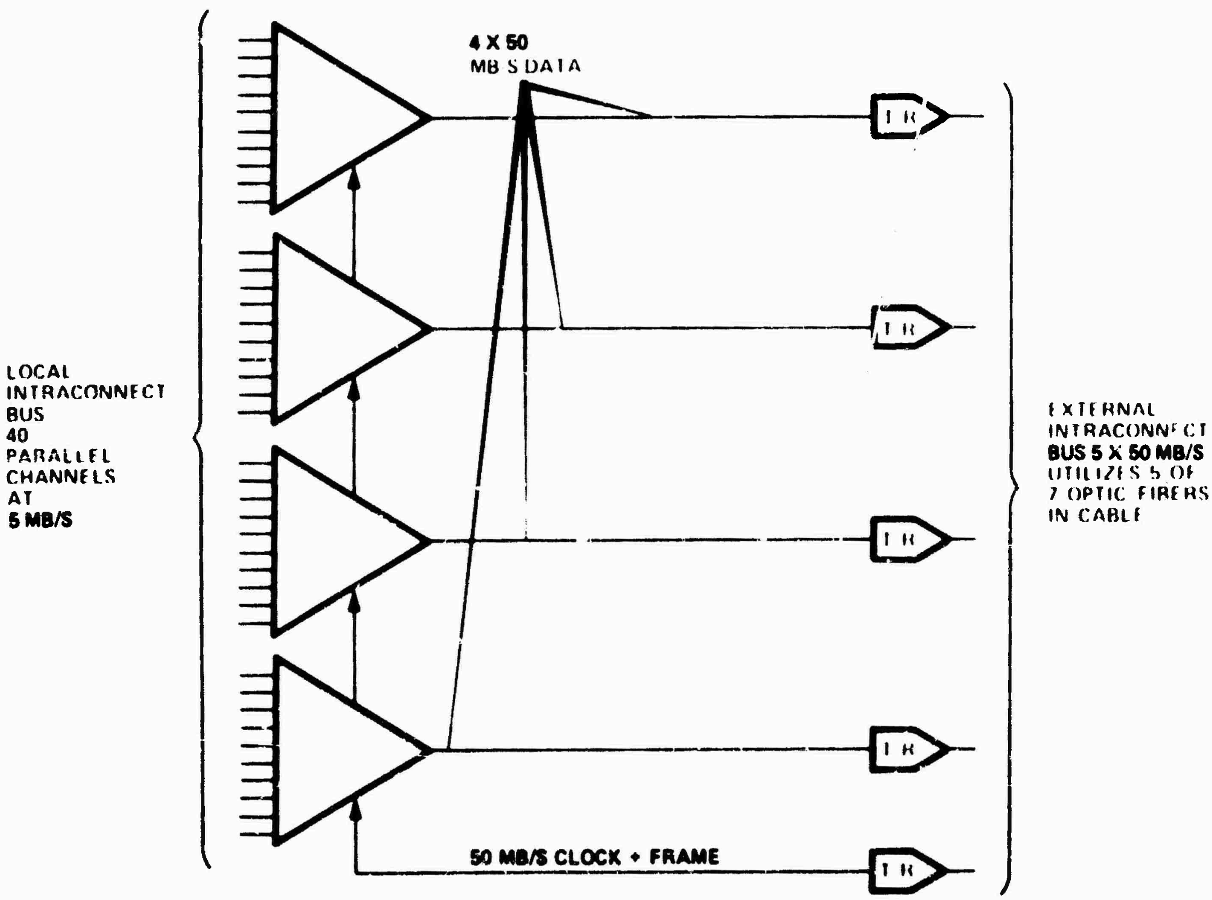


Figure 3-3 TDM-SDM.

After conversion by the EIU to the 40-channel bus electrical format, bus data are applied to the LICU at the shelter wall. The LICU is the interface between the intershelter and intrashelter bus systems. In interfacing the intershelter bus, it acts as a slave unit and only responds when it is polled by the EICU.

3.2.2 Intrashelter bus. On the intrashelter bus side, the LICU acts as the bus controller and performs three major functions:

a. At all times when there is no external-to-internal bus data interchange, the LICU continually polls all terminal devices on the internal bus in sequence (according to priority), allowing them to interchange data with each other and with the LICU.
b. When a device on the internal bus has data to be transmitted on the external bus, the LICU buffers and then transmits the data when polled by the EICU.
c. The LICU receives all external bus data and interprets both the address and data-type coding. If the address or the data type are addressed to its intrashelter bus, the LICU buffers the data and retransmits it in sequence with other data on the intrashelter bus.

The intrashelter bus data are transmitted bidirectionally on a 40-conductor, twisted-pair ribbon cable. The data on this bus are formatted as a 36-bit parallel data word transmitted on 36 of the conductors at a 5 megaword/second (Mw/s) rate. One of the remaining four conductors carries a 5 MHz clock, and the remaining three conductors carry control bits at 5 Mb/s rate each. The bus operates on a demand-response basis under control of the LICU, which controls the access of each local intraconnect unit (LIU) to the internal bus, and interfaces the internal bus and the external bus as necessary. Under normal circumstances, the LIU will be allowed to intercommunicate without interference from the external bus. Each LIU responds to a poll from the LICU upon recognition of its address in the polling transmission. The polled LIU responds with its own status response and any data being transferred to another LIU via the bus. When the LICU receives external bus data, either addressed to a LIU within its control (or data of a type it is programmed to pass on to the internal bus), the LICU buffers that data and retransmits it on the internal bus as soon as the current transmission on the internal is finished. If data on the internal bus are addressed to an external bus, or the data are a type the LICU is programmed to pass on to the external bus, the LICU will buffer and retransmit such data externally as soon as it is polled by the EICU.

The polling mechanism in the LICU can be designed for programming with either a simple fixed-sequence polling algorithm (as required in SCC-1, -2 and -3) or with a more complex, dynamic polling algorithm as required in SCC-4A and 4B.

Each device interfacing the internal bus does so through a general-purpose LIU. This unit (Fig. 3-4) consists of the modems (line drivers and receivers) necessary to interface electrically with the 40-conductor twisted-pair internal bus and the terminal device being serviced. The LIU also contains a buffer; a microprocessor subsystem to handle the internal bus protocol, direct input/output of the buffer in both directions, and handle the protocol between the LICU and the device it is interfacing.

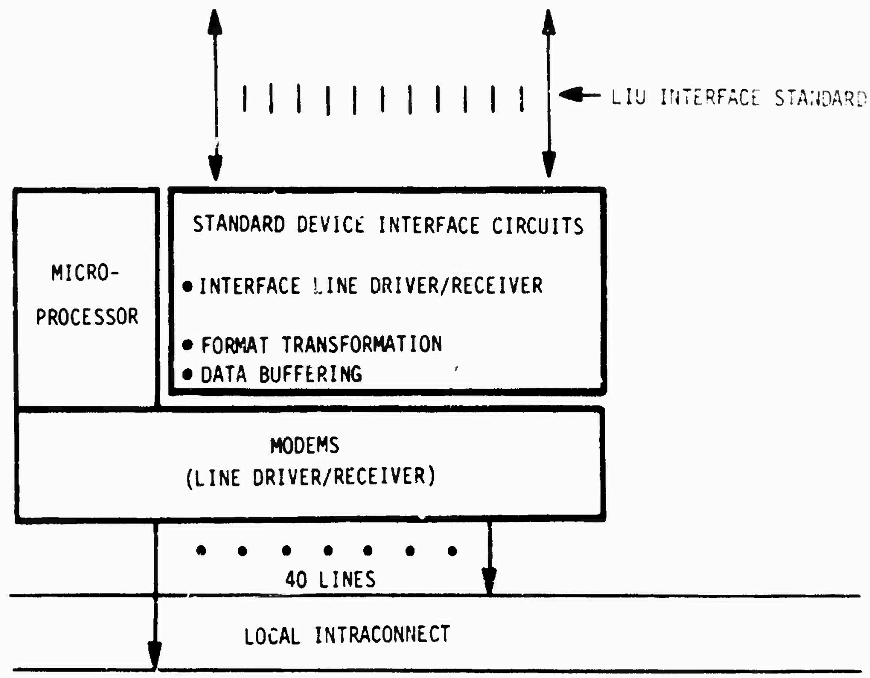


Figure 3-4. General purpose local intraconnect unit.

In some cases, to provide interfaces with specific existing terminal devices, an adapter must be added to the LIU as illustrated in Figures 3-5 and 3-6. As shown, the adapter provides specific electrical interface with the device and, via firmware connected to the microprocessor, performs the necessary protocol with the device under processor control. As illustrated in Figure 3-5, a single LIU can provide the interface for up to 10 relatively low-speed communication devices (under 100 kb/s). For ADP devices which are higher speed, an LIU can interface only a single device (Fig. 3-6). Many existing families of ADP equipment that include CPUs, disks, magnetic tape units, paper tape units, operator consoles, etc., have been designed for operation on a common bus within each family. These peripherals will interface with the flexible intraconnect through identical adapters as shown in Figure 3-7. Until the standard interface is widely adopted, the hardware adapters and the programmable microprocessor in the LIU can provide the transformations required between the characteristics of the device interface and those of the standard LIU interface to enable data interchange between ADP devices with nominally incompatible interfaces. An arbitrary processor with its own standard interface can communicate with the bus via an LIU containing an adapter. The adapter function translates data into a common format for transmission via the internal bus. An arbitrary peripheral, operating under a different standard interface, can be translated into the common format by another adapter. In this manner, data to and from both devices will exist on the bus in a common format, which will be accepted by each LIU and translated into the format of the respective terminal device interface.

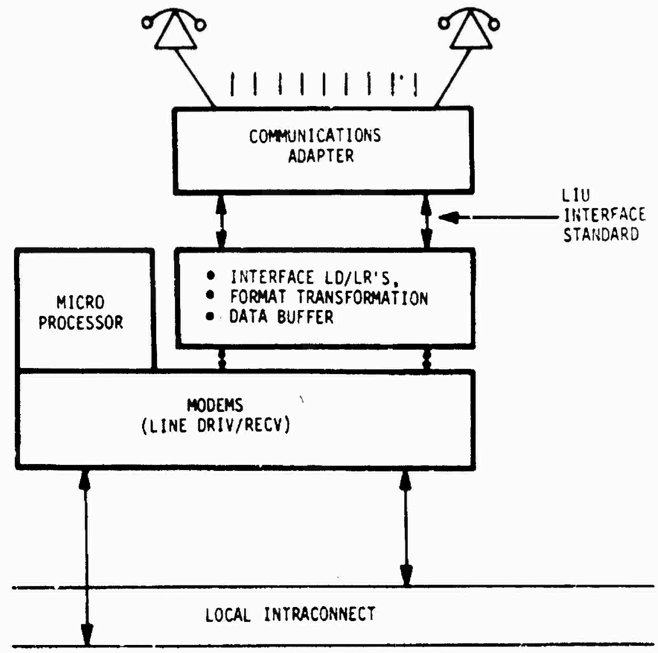


Figure 3-5. Local intraconnect unit interfacing ten telephone users.

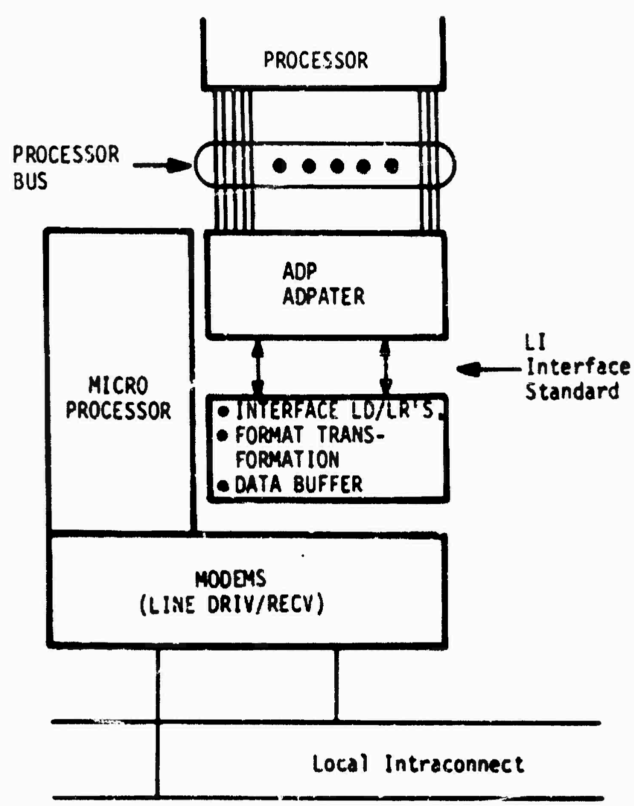


Figure 3-6. Interfacing ADP device.

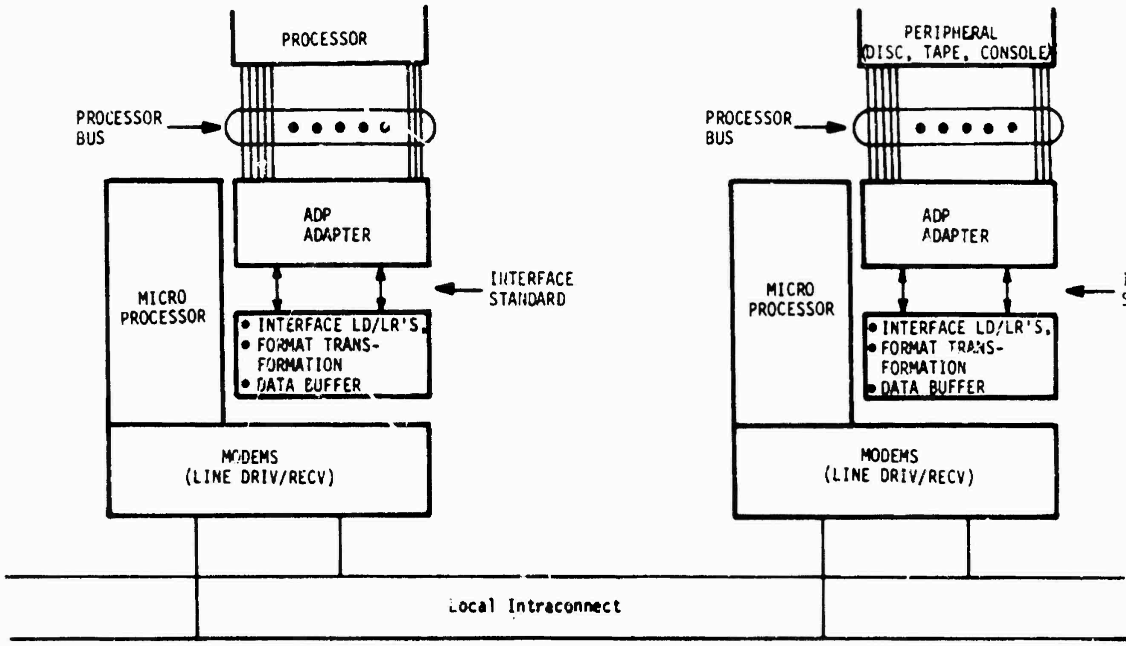


Figure 3-7. LIU interfacing ADP and peripherals.

The LIU will be a flexible unit capable of being programmed to transform formats of existing and interim ADP and communications equipment. In the future, new equipment using the FI will be designed in accordance with the standard interface making adapters unnecessary.

3.2.3 Evolving configurations of recommended system implementation. Recommended two-level bus architecture permits the Flexible Intraconnect to evolve from the present dedicated-circuit configuration (with patching performed in a separate technical control and switching in a separate centralized switch) into a higher capacity demand-access configuration retaining separate patching and switching facilities, and further into the ultimate configuration in which patching and switching are inherent features of the bus architecture, eliminating many requirements for the switch and tech control facilities to provide such functions. There are three phases in the evolution process.

Phase I corresponds to SCC-1, -2, and -3 and replaces each circuit in the current intraconnect with a static-dedicated message block on the bus. Bus access is controlled through a simple fixed-polling sequence.

Phase II, corresponding to SCC-4A, includes a priority-polling algorithm permitting bus message blocks to be dynamically dedicated to active users only, i.e., those which are off-hook, thus increasing the available bus capacity. Where over 40 percent of the bus capacity in Phase I is required for communications traffic, this is reduced to 15.5 percent in Phase II even though traffic loads are slightly higher. The bus capacity balance is available to serve growing ADP traffic needs. The change from static to dynamic-dedicated message blocks is accomplished through software changes in the EICU and LICU. For both Phase I and Phase II, separate centralized patching and switching are retained.

Phase III corresponds to SCC-4B. By modular expansion, circuits can be added to the LICU providing such call processing functions as loop-loop signaling, conferencing, and priority overrides. The inherent distributed switching capability of the polled-bus system is used in Phase III to augment and replace some functions in the circuit switch and technical control facility.

Summaries of the recommended intraconnects for each of the three phases of the evolution is discussed in the following subsections.

3.2.3.1 Phase I (SCC-1, -2, and -3). The two-level bus intraconnects all elements of the C^3 center and provides dedicated message blocks exactly duplicating the wire runs of the current intraconnect. A 32 kb/s space on the bus is allocated for every intershelter circuit in the present system, which it replaces. To accomplish this without modifying present shelter designs or impacting current C^3 equipment developments for SCC-1, -2, and -3, the EIU, LICU, and all LIUs can be housed in a box external to the shelter. The communications LIUs will interface directly with the 26-pair cable connectors at the shelter wall as illustrated in Figures 3-8 and 3-9.

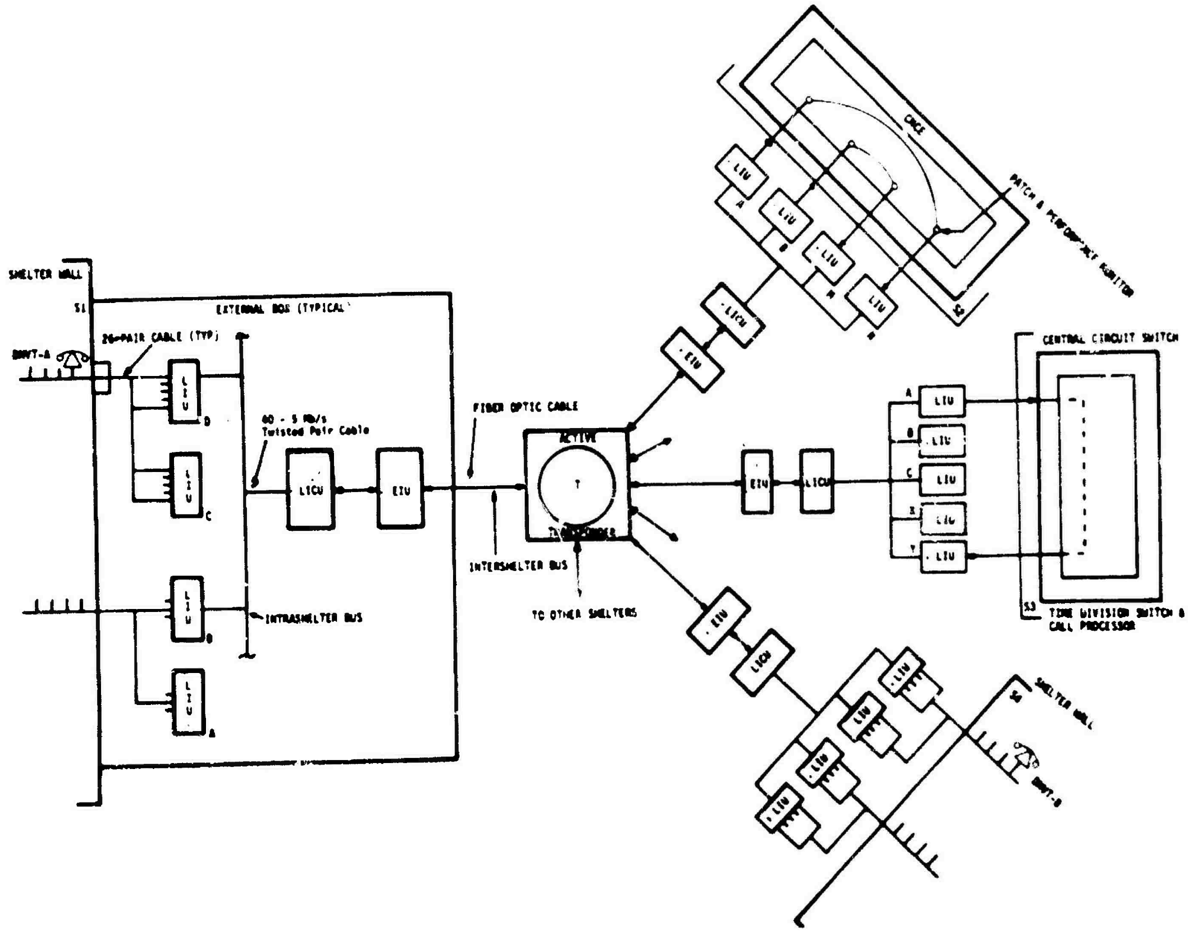


Figure 3-8. Implementations, phase 1.

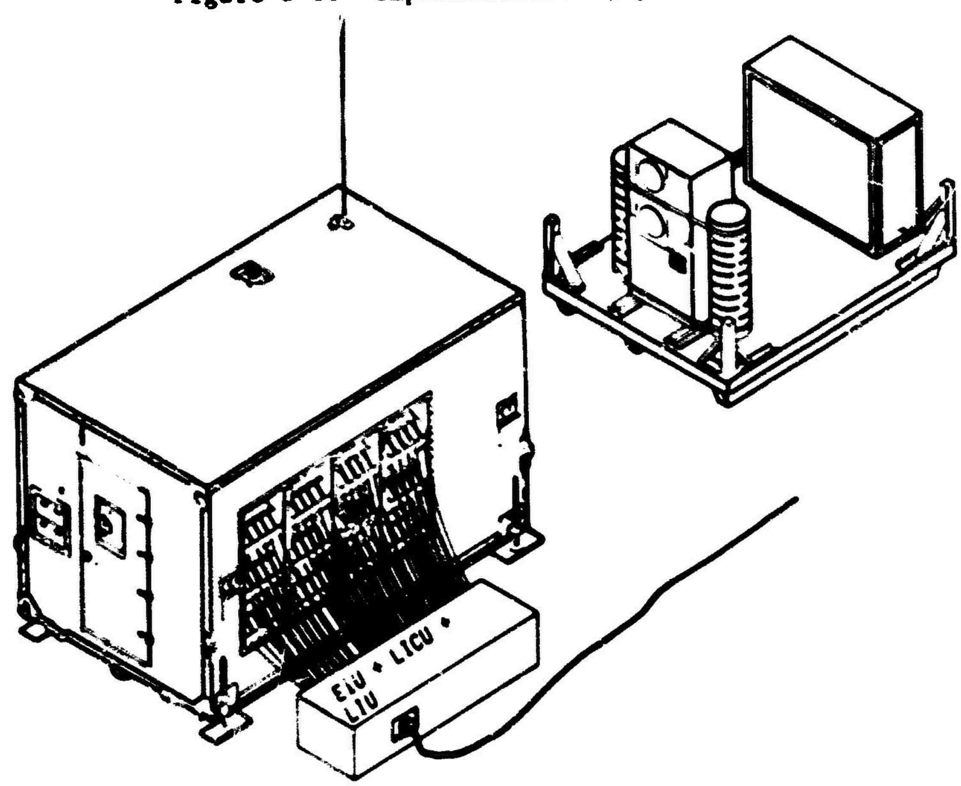


Figure 3-9. Implementations, phase 1.

Intershelter and intrashelter bus access is provided by statically allocating message blocks and by fixed-sequence polling algorithms in both the EICU (for intershelter) and the LICU.

3.2.3.2 Phase II (SCC-4A). In Phase II, the intraconnect protocol is changed to a dynamic access approach by allocating message blocks only to active users. Each subscriber's status (active/inactive) is monitored and space dynamically allocated while the subscriber remains active. The difference in the implementation between Phase I and Phase II is in how the user-device seizes and releases space on the bus, and in time dedicated to each shelter on the intershelter bus and to each LIU on the intrashelter bus. The same packet transfer will be performed to provide the intraconnect service for the telephone transmission from DNVTs as performed in Phase I.

3.2.3.3 Phase III (SCC-4B). In Phase III, circuits are added to the EICU to provide call processing functions such as address translation, classmarked service, and external interface controls. The additional processing functions allow realization of the benefits of the distributed packet switching capabilitities, which are inherent advantages of the bus system concept. Distributed packet switching on the bus can eliminate the need for many functions performed in the circuit switch and technical control facility in the post-1995 period.

Phase III implementaion of the recommended intraconnect is shown in Figure 3-10. The major differences between this system and the Phase II system are:

a. The intrashelter bus, EIU, LICU, and LIU are all housed internal to the shelter;
b. A single connector on the shelter wall for a multi-fiber cable to the transponder is the only flexible intraconnect cable connection required to communicate with other shelters in the center;
c. The terminal devices interface directly with their LIUs, eliminating the 26-pair cables within the shelter;
d. Bus capacity for ADP equipment is significantly increased; and
e. The appearance of the call processing function in the EICU.

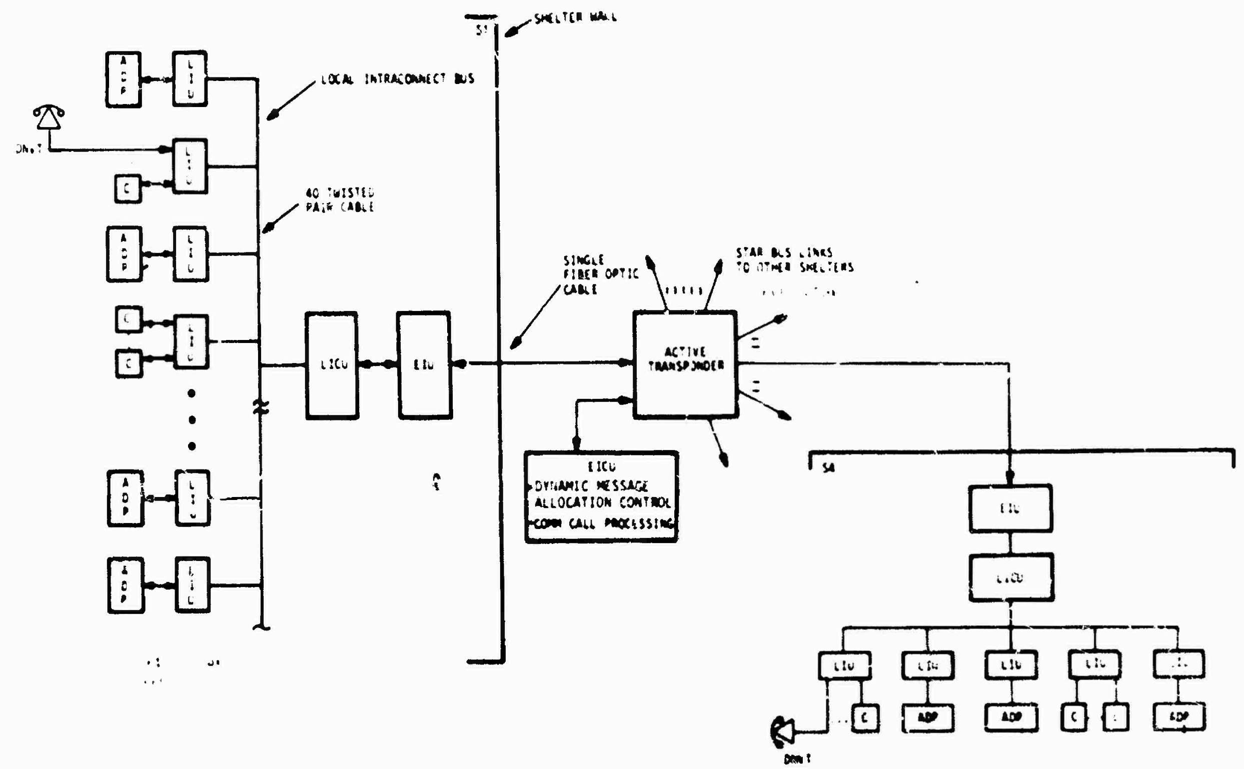


Figure 3-10. Phase III implementation of recommended system.

3.2.4 Physical aspects of bus design. At present, an equipment shelter at a TACC or CRC/CRP intraconnects to the remaining elements at the C^3 center via numerous CX-4566 26-pair cable assemblies. One example of this is the technical control communications central (AN/TSC-62) shown in Figure 3-11, which has 60 26-pair cable "connectors" on its side wall. From these connectors, cables run in all directions to other shelters within the center, frequently passing over the shelter as illustrated to relieve congestion.

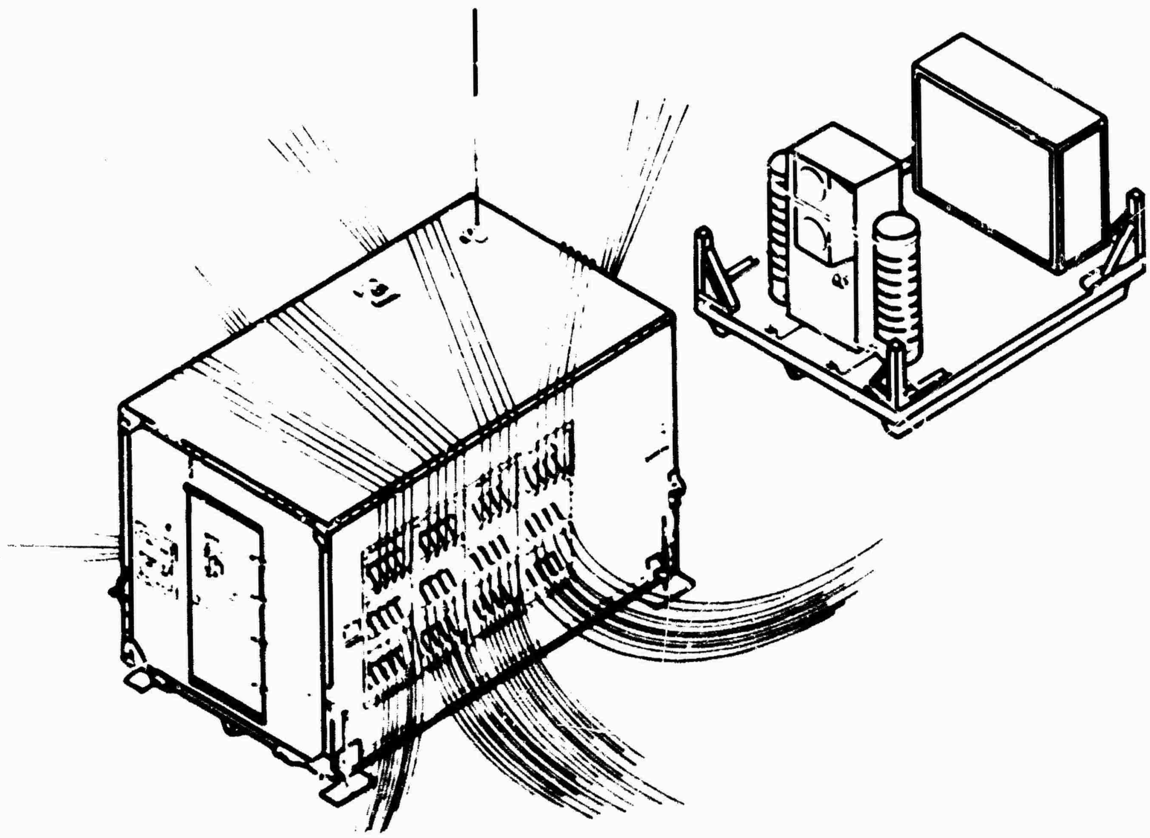


Figure 3-11. Communications central AN/TSC-62 (present cable system).

In future equipment designs, the recommended flexible intraconnect bus will replace all these cables with a single cable as shown in Figure 3-12. This fiber-optics cable will contain multiple optical fibers. A seven-fiber cable is shown in Figure 3-13. The cable, 6.4 mm (0.25 inches) in overall diameter, has a polyurethane inner jacket surrounding the optical fibers surrounded by Kevlar-strength members, helically laid. A layer of Teflon tape surrounds the strength members followed by an outer jacket of polyurethane. The Kevlar-strength members provide longitudinal tension strength, the two polyurethane jackets provide padding for protection against crushing as well as weather protection, and the Teflon tape provides stress relief between the inner and outer members during bending.

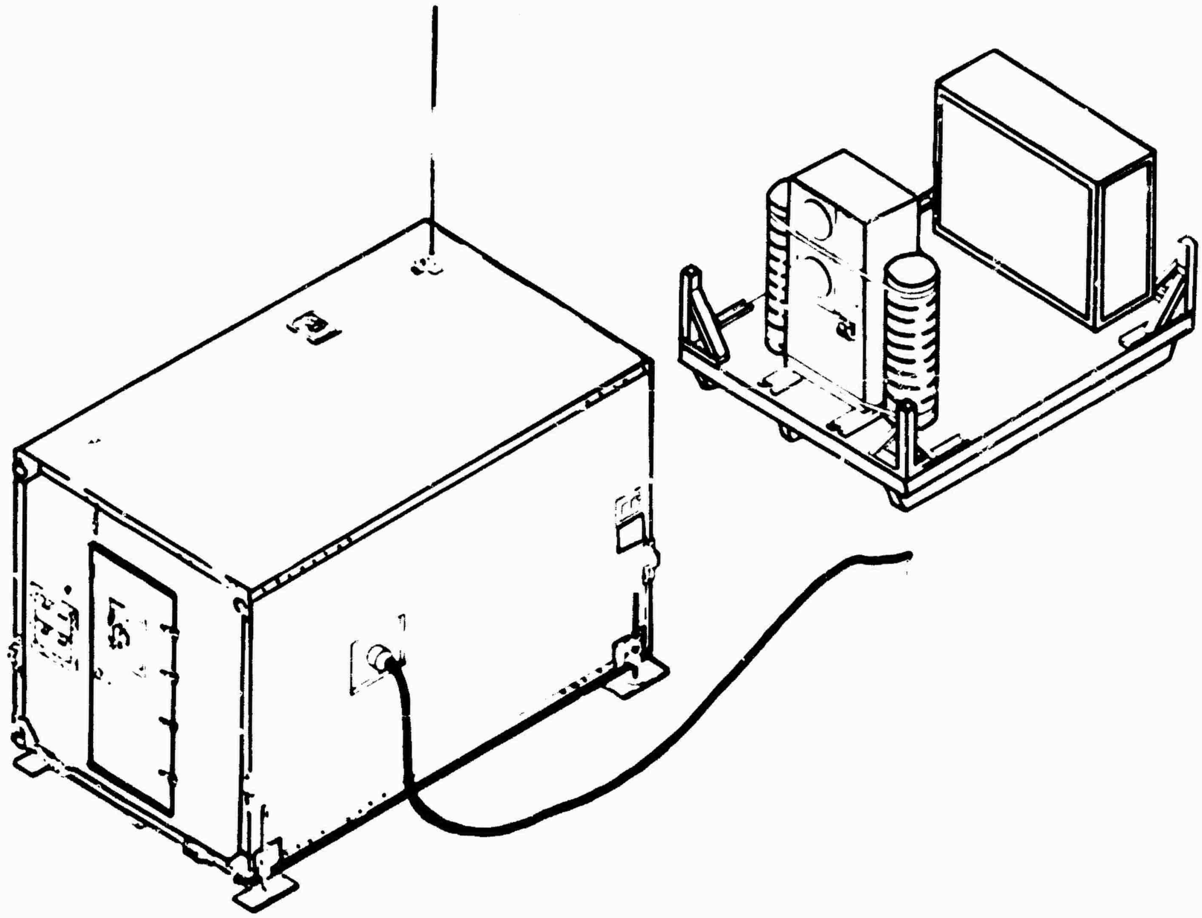


Figure 3-12 Communications central AN/TSC-62 (recommended system).

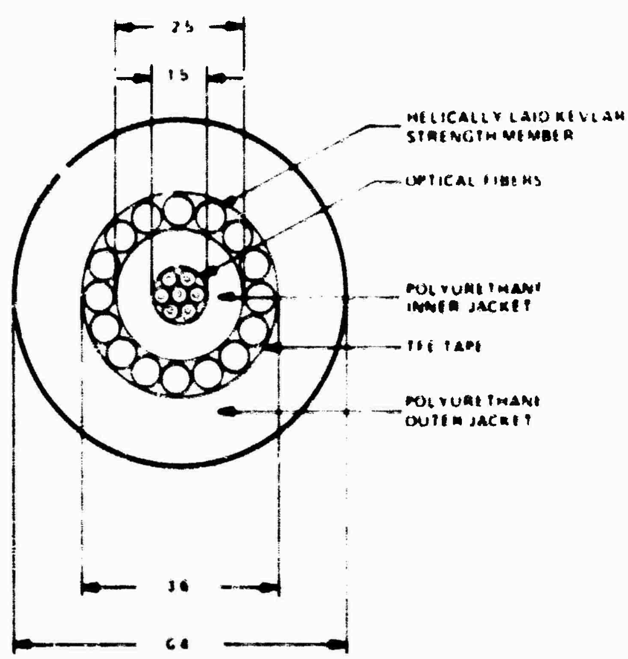


Figure 3-13. External strength member - 7-fiber cable.

It is acknowledged that a single cable Flexible Intraconnect bus cannot be fielded and plugged directly into the existing shelters with their multiple 26-pair connectors on the wall, nor is it recommended that existing equipment be remanufactured to convert from the multiple 26-pair connectors to the single seven-fiber optical connector. Instead, the EIU can be mounted initially in an external box along with all the LIUs, for communications devices (Fig. 3-9). This external box would interconnect to the existing 26-pair cable locks on the shelter walls via pigtails and convert to the single seven-fiber optical cable as shown. For transport, this external EIU/LIU box could mount on the air conditioning pallet as illustrated.

4.0 OPERATIONAL REQUIREMENTS

The Operational requirements of the FI have evolved throughout Phase I. Through the exchange of operational and functional concepts between the government and this contractor, system requirements have experienced several levels of refinement. Many specification parameters have been defined in considerable detail during Phase I. However, they have not at this time been compiled into a composite specification.

An overview of the operational requirements is given in this section. They are also discussed in detail along with the conceptual design of the FI in Sections 5.0 through 10.0.

4.1 FI architecture.

The FI architecture developed in Task I and II of the study defined the requirement for a two-level bus transmission system; one bus to carry the Local (intrashelter) traffic. Figure 1-2 illustrates the general configuration required to meet the traffic requirements defined for the C^3 equipment centers.

The external intraconnect (EI) must be constructed on a star topology with legs emanating from an active transponder to provide each shelter on the FI with up and downlink communications. The EI must provide the transmission facility for both bidirectional digital traffic between the devices on local intraconnects (LI) in different shelters, and unidirectional, high-speed analog traffic used mainly to support the video and azimuth/elevation signals from the radar shelters to the operations central shelter. The digital EI traffic must be switched and regeneratively repeated in the transponder and the data radiated out to all shelters on the EI. The analog signals are to be semi-permanently patched on dedicated channels through the transponder, repeated if required, and transmitted downlink only to the shelter housing the destination device.

The number of legs on the EI star up and downlinks (digital and analog) between shelters and the transponder must be adaptive to meet the needs of both large and small TAF centers, without inordinately taxing the small centers. The maximum number of legs on the EI is limited to 63. The required maximum number of EI legs identified during the traffic study of Task I was 19. Thus; the requirement for 63 legs will provide a good margin for future growth.

The digital intershelter traffic requirement defined in the traffic analysis of Task I was 150 Mb/s (data, overhead and margin) maximum for SCC-4B. The system requirement that the EI transmission facility be capable of adapting to various rates up to 200 Mb/s has been defined and exceeds the requirements with a 25 percent margin.

The transponder is required to perform the functions listed below for the FI to provide a switched-active star EI communication facility between shelters.

a. Accept digital data from each shelters uplink,
b. Select the appropriate digital uplink for retransmission,
c. Regenerate the selected uplink signals,
d. Transmit the selected data signals to all the shelter downlinks on the EI; and
e. Provide through patching for the dedicated analog channels.

Security requirements imposed on the EI are protection from breach of privacy and traffic flow security. Encryption is required on all data transmitted intershelter on the EI. Furthermore, continuous transmission is required on each uplink to provide the required traffic-flow security. This consists of a pseudorandom sequence interspersed with valid data packets. Also, no information may be placed on the data lines or any clock or synchronization lines which will indicate when messages start or stop.

The local intraconnect (LI) is required to be constructed on a parallel open-loop topology that can support up to 64 Local Intraconnect Units (LIUs). The LI must provide the transmission facility for bidirectional digital traffic beteen devices within the shelter. The LI bus is to provide up to 360 Mb/s transmission over 300 ft. of LI bus cable. The LIU is required to provide the interface and LI bus access faclity for the devices serviced by the FI.

The LI interface specifications, device/LIU interface (defined by the FI Interface Standard), and the LI bus interface are required to be rigid. The burden to be compatible with the FI is placed on the user devices; the intention being that new equipment designs, which are to use the FI, will provide an FI compatible interface. Rigid interface specifications are intended to provide for a single LIU design to service all device types using the FI. Devices not compatible with the FI Interface Standard are required to interface the LIU through a selected adaptor unit (SAU). SAUs will be provided by the FI to provide format and signal transformation and the protocol functions required to access the FI.

4.2 FI subnetworks.

There is a requirement to establish networks within the Flexible Intraconnect to serve special needs of FI users. These subnetworks are established through the network controller or the FI Manager, and operate at a level of system protocol entirely within the confines of the FI, i.e., transparent to device protocol. The following subnetworks can be established on the FI:

4.2.1 Direct address. A direct address network is the most basic mode of transmission over the FI. It is used for the direct transfer of messages between two devices and is, therefore, a two-party network (Fig. 4-1). The data transfer rate is fixed. The communication can be simplex or duplex and a point-to-point network can be set up by command/response messages betwzen the FI Manager and the participating devices.

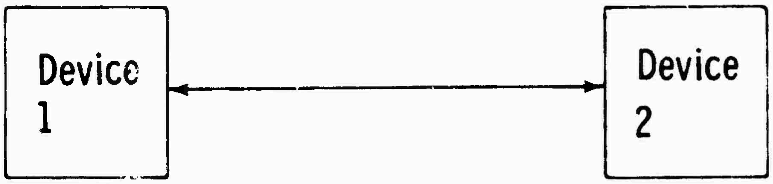


Figure 4-1. Direct address transmission.

4.2.2 Virtual bus. A virtual bus is a network wherein all participants on a particular virtual bus network transmit at selected rates to all other participants, and transmissions from any one is received simultaneously by all others (Fig. 4-2). There may be up to 63 virtual busses on the FI. A virtual bus may operate at any rate up to a maximum of 10 Mb/s.

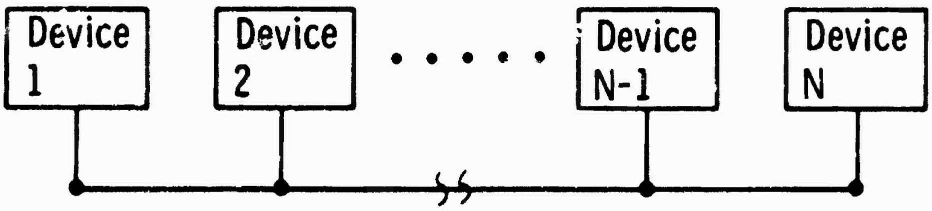


Figure 4-2. Virtual bus.

Devices participating on a virtual bus transmit in a sequence fixed by the FI Manager. A device will transmit to all other devices on the virtual bus when its order in the sequence comes up. The rate at which a device is programmed to transmit determines its repitition interval in the format of the virtual bus. A virtual bus provides the capability for a device to transmit data to a number of other devices at a given rate of transmission. A device may transmit to any or all devices on its virtual bus.

4.2.3 Lazy susan. In a lazy susan network, messages are transferred from one device to another in a serial closed loop (Fig. 4-3). Upon receipt of a single message block, each device holds it for a fixed interval during which it may alter, or add to its contents before passing it to the next device. There may be up to 63 shelters participating on any one lazy susan bus; i.e., any one bus may traverse the EI up to 63 times from the originating (master) device to the last device on the network. However, a lazy susan network may operate at a fixed rate to to 10 Mb/s maximum. There may be up to 63 lazy susan networks on the FI, and they may have a composite rate of up to 20 Mb/s. A lazy susan network may be set up among several ADP devices where different sources contribute component parts to a composite array of interacting data.

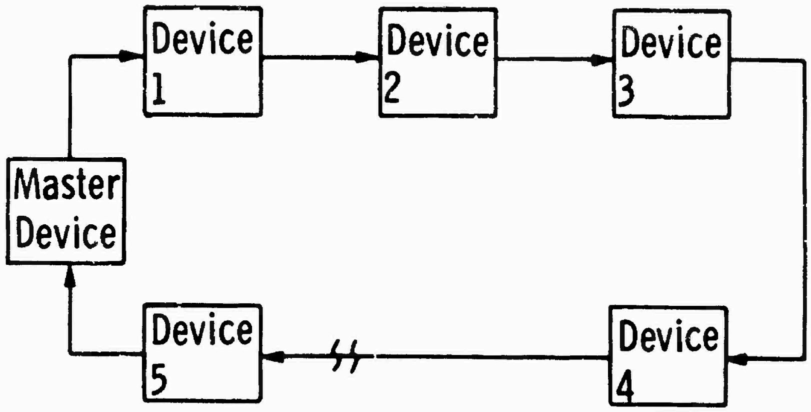


Figure 4-3. Lazy susan bus.

4.2.4 Broadcast. A broadcast network is one in which any participant may simultaneously transmit a message block to all other participants (Fig. 4-4). A broadcast network will typically have a few source devices and many passive recipients, although any or all participating devices may transmit if so programmed by the FI Manager. A broadcast network may be set up as a local broadcast, or an all-FI broadcast. In a local broadcast, participation is limited to devices on one LI whereas an all-FI network can include any device on the FI. A local broadcast transmission will not go over the EI. The broadcast network is useful in dissiminating data from high-density information sources to large numbers of passive recipients.

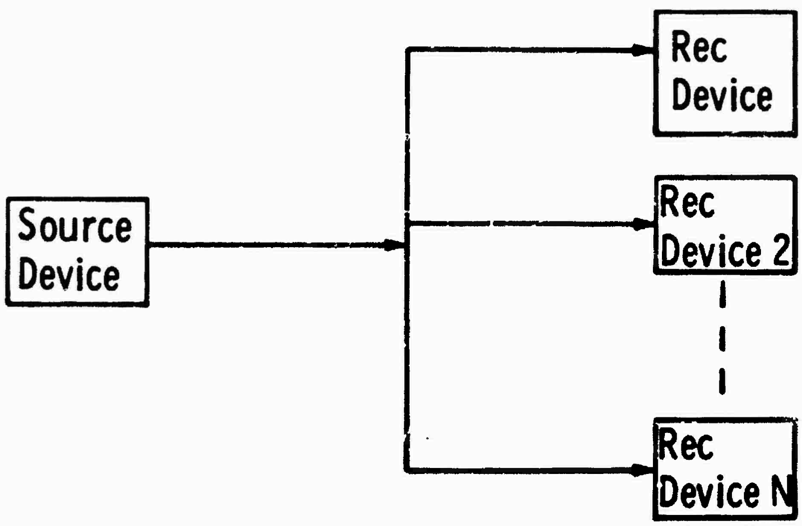


Figure 4-4. Broadcast network.

4.3 FI control functions.

The FI functions under the supervision of a communications control officer to support the data transmission demands of the ADP and comm terminal equipment. These equipment comprise a variety of data rates and structures. The FI control system design must be adaptive and flexible to meet these demands. The requirements and implementation of the system controls required

to meet these requirements are discussed in detail in Section 5.3. Therefore, the requirements will not be discussed again in this section. The aspects of system control which were studied in Task III are listed below for ease of reference.

- System Initalization Control
  - Database Generation
  - EI Initialization
  - LI Initialization
- Device Net Configuration Control
  - Establishment
  - Modification
  - Termination
- Data Transmission Control
  - Data Transfer Protocols
- Database Management
- Error Control
- Failure Control
  - Graceful Degradation
- Resource Management

4.4 Interface design.

The LI interfaces have been defined in Phase I except for their electrical signal characteristics. Their characteristics are discussed in detail in Section 6.0 and 5.1.2 respectively, and will be listed briefly below.

Device/LIU interface - The interface between the Device and LIU is defined by the FI Interface Standard as described in Section 6.0. The data transfer characteristics at the interface are:

a. Data Transfer Controller: LIU;
b. Data Transfer Type: DMA,
c. Word Size: 18 bits (2 folded 9-bit words);
d. Message Size: 1-to-1024 words max;
e. Transfer Rate: 10 Mw/s max (determined by device); and
f. Data Transfer Control: Device/LIU protocol (defined by FI Interface Standard).

The same interface characteristics also govern data transfer between the LICU and the EIU.

LIU/LI bus interface - The LI bus interface characteristics (also discussed in Section 5.1.2) are listed below;

a. Data transfer type: DMA;
b. Word Size: 36 bits (2 folded 18 bit words);
c. Message Size: 1-to-512 words max;
d. Transfer Rate: 10 Mu/s max (defined by system clock);
e. Data Transfer Control: Device/LIU Protocol; and
f. Data Transfer Controller: LICU grants bus control to polled LIU.

The EI external shelter interface is tentatively defined as four-channel fiber optic up and down channels. The interface is defined in Section 5.2.4.

a. Data Transfer Type: TDMA;
b. Word Size: 36 bits;
c. Byte Size: 4 bits parallel;
d. message Size: 1-to-512 words; max;
e. Transfer Rate: 50 Mb/s per channel;
f. No. of parallel channels: 4 channels @ 50 Mb/s yields a 180 Mw/s;
g. Data Transfer Control: not defined but, probably will be defined about the same as the LI bus; and
h. Data Transfer Controller: EICU grants control to the polled EICU.

4.5 System error performance.

System error performance required on data transmission through the FI were preliminarily specified during Task III. The two aspects of error control that were defined are the protection of user data against undetected errors, and misrouting data to the wrong destination. The preliminary specifications for both control functions are listed below.

4.5.1 Data Error.
Requirement:
1×10^{-12} Undetected Bit-Error Rate (BER)
Assumptions:
1×10^{-8} Inherant Channel BER
Errors Statistically Independent
Action:
Upon detection of an error in the data block the data is to be discarded and an error message sent to the destination device.

4.5.2 Header Error.
Requirement:
5,000 years mean-time to undetected header error.
Assumptions:
5,000 Messages/s.
1×10^{-8} Inherent Channel BER
Errors Statistically Independent
Point-to-Point Transmission Assumed
Header $\equiv$ FI Network Header & Device Header
Action:
Upon detection of an error in the header, the data is to be discarded and an error message sent to the FI Manager.

5.0 SYSTEM DESCRIPTION

The FI is a packetized digital transmission and switching system designed to provide the voice and data (digital and analog) communications interconnection among user devices within a TAF center. Figure 5-1 illustrates the two-level bus system consisting of a Local Intraconnect (LI) which provides the intrashelter communication between user devices, and an External Intraconnect (EI), which provides the communication between shelters.

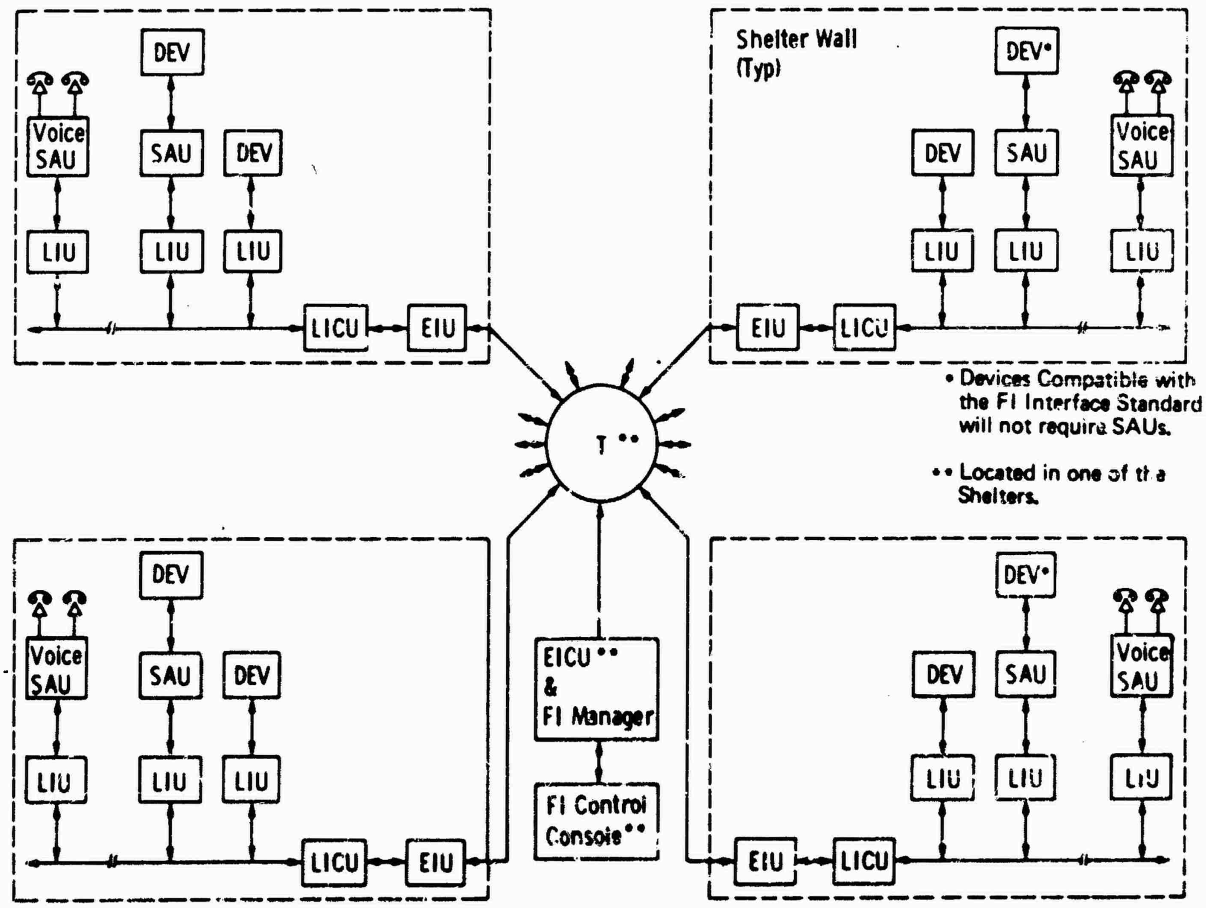


Figure 5-1. Flexible interconnect system.

The LI is an open-loop bus consisting of up to sixty-four Local Intraconnect Units (LIUs) which provide user device access to the LI. Devices whose input/output characteristics (hardware and software) are compatible with the LIU/Device Interface Standard (discussed in Section 6.0) may be connected directly to the LIU. If not, the necessary compatibility conversions are performed by a Selected Adapter Unit (SAU), which is considered as a part of the FI equipment. LIU access to the LI bus is controlled by the Local Intraconnect Control Unit (LICU). The LICU polls each LIU in a controlled sequence according to polling algorithms to coordinate the transmission of the data onto the bus in formatted message blocks or packets. When a device on

one shelter LI is to communicate with a device on another shelter's LI, the data packets must be transmitted over the EI. The packets are buffered in the LICU and transferred to the EI via an External Intraconnect Unit (EIU) which provides an LI access to the EI bus in a manner similar to the LIU providing a device access to the LI bus. Operation of the LI is discussed in Section 5.1.

The EI consists of multi-conductor fiber optic cables arranged in a star topology to connect each equipment shelter, via an up link and a down link, with a centrally located active switching transponder. Both the up and down link consists of four parallel 50 Mb/s data channels for a composite of 200 Mb/s duplex transmission, between each shelter and the transponder. There may be as many as 63 legs (LIs) in the star configuration. Access of an EIU to the EI bus is controlled by the External Intraconnect Control Unit (EICU). The EICU polls each EIU in a controlled sequence, according to the EI polling algorithm (similar to LI polling) to coordinate the tramsmission of data packets between shelters. The operation of the EI is discussed in Section 5.2 and Volume II.

The FI is an adaptive system that can be modified as center requirements change. Device networks are configured (established, modified and terminated) under interactive control between select controling devices and the FI Manager. The controling devices request the FI Manager to modify the FI to change device network configurations. In return, the FI Manager, determines whether to grant the device requests, and if granted, modifies the FI polling algorithms to enact the new device network configurations.

The flexibility built into the polling control function, and the ease of modifying the polling algorithms provides the adaptability needed for ease of FI system evaluation. The adaptability of the polling mechanisms is manifest in the ability to evolve from a relatively simple, fixed sequence algorithm required in SSCs 1, 2, and 3 to a complex dynamically dedicated priority polling algorithm in SSC-4A and 4B.

The FI is a distributed control system that operates under the configuration of the FI Manager. The FI Manager determines polling algorithms for both the EI and every LI in the system. It also controls the loading of the algorithms in the EICU and LICUs. Once the LI polling algorithm is loaded in the LICU the packet transmission on the LI is conducted independent of the rest of the system, except for intershelter packet transmission. The EI also operates independently from the rest of the system after its polling algorithm is loaded. The distributed data transfer control provides the system with a strong error control function for degraded operation. The LI can continue to provide intrashelter data transfer service upon EI failure, FI Manager failure, or failure in any other LI. The same is true for the EI transmission, which continues when one or more LIs fail. The FI system control will be discussed in Section 5.3.

5.1 Local intraconnect operation.

The LI is the subsystem of the FI that provides the facility for packetized voice and data (analog and digital) transfer between devices within the shelter. Figure 5-2 illustrates the LI block diagram. The LICU acts as the LI bus controller and, in this roll, performs three major functions:

a. When there is no EI/LI bus data interchange, the LICU continually polls LIUs on the LI bus in an ordered sequence according to its polling algorithm, allowing the resident devices to interchange data with each other;

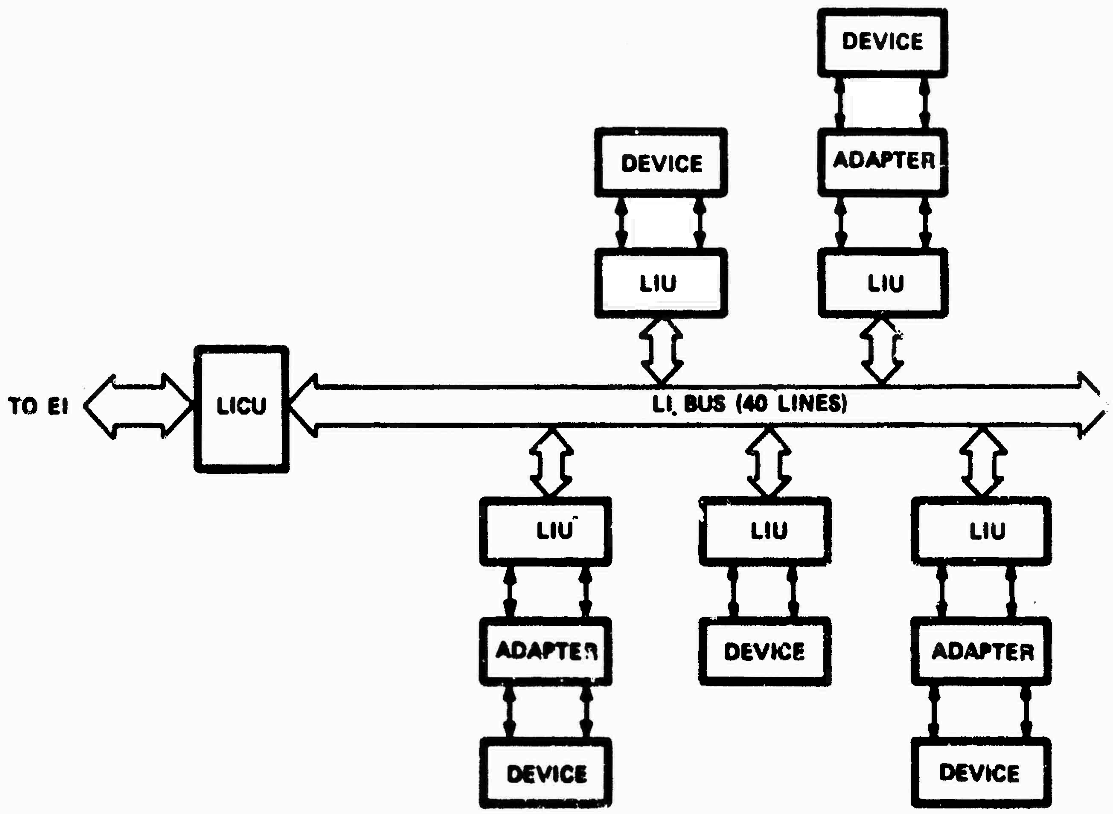


Figure 5-2. Local intraconnect.

b. When a device resident on the LI has data to be transmitted over the EI to a device resident on another LI, the LICU buffers the data and then transfers it to the EI via the EIU; and

c. The LICU receives all EI data destined for the LI, buffers it, and retransmits the data over the LI bus immediately following the end of the response packet from the most recently polled LIU.

The LIU transfers the device's (SAU) data message into its buffer, formulates the network header for transmission control, packetizes the device message and network header, and when polled, transfers the packet onto the LI bus for transmission to its destination device. The LI bus data and control signals are transmitted bidirectionally on a 40-conductor twisted-pair ribbon cable. The data is transferred between the LIUs and LICU on a demand-response Time Division Multiple Access (TDMA) basis, with LI bus access provided on a polling basis. The data transmission is formatted on a packet-serial, word-serial, bit parallel (TDM, TDM, SDM) basis as shown in Figure 5-3. In this way each LIU and the LICU monitors every packet transmitted over the bus. The LIU analyzes the packet network header to determine if the packet is destined for itself and, if so, what response it is required to take. An LIU must respond in a specific manner to each of the three basic packet types directed to it. The packet types are discussed below.

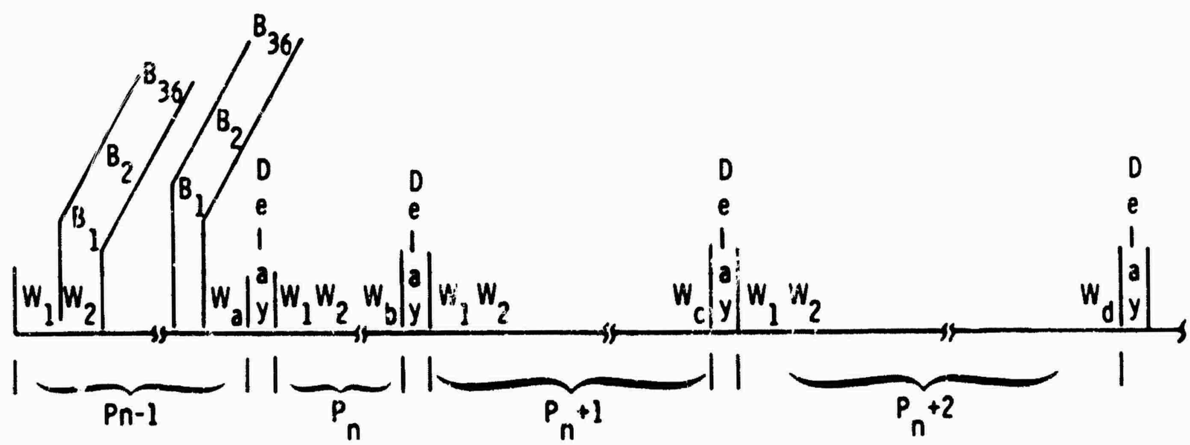


Figure 5-3. LI transmission format (TDM/TDM/SDM).

a. Poll packets. The LICU polls an LIU by transferring a short poll packet containing the LIUs address and a poll message code (See section 5.3.3). Upon recognizing its address as the destination of the poll packet, the LIU must respond with a poll response packet whether or not it has device data to send. If it has received a message from the device for transmission, it will transfer a data packet on the LI bus in response to the poll. If not, it will transfer an idle packet onto the LI bus. The only exception occurs when a query/response procedure is required before transferring a direct-address data packet (discussed below). The LICU recognizes the completion of the poll response packet transfer on the LI bus, it then polls the next LIU in the polling sequence.

b. Query response packets. For direct address messages only, a query/response procedure must be engaged in between the source and destination LIUs. When the source LIU is polled, it sends a short query packet to the destination LIU, inquiring if it has buffer space available to accept the data. The queried LIU recognizes its address in the packet header along with a query code in the message type field (see Section 5.3.3). Upon recognition of the query, the destination LIU formulates a short response packet addressed back to the source LIU indicating the availability of its buffer to accept a data packet. It then transfers the response packet immediately onto the LI bus without waiting for a poll from the LICU. If the response is affirmative, the source LIU transfers the data packet onto the LI bus immediately without waiting for a poll. If not, the source LIU must wait for the LICU to determine when the destination LIU has buffer available and informs it, in a poll message, to send the data packet to the destination LIU. The same query/response procedure occurs between the source LIU and the LICU for direct address data transmission to an LIU on another LI. The query/response procedure will be detailed in Section 5.3.3.

c. Data packets. Data packets are exchanged between LIUs (or LICU) on the LI to provide the facility for data transfer between devices on the LI. The data transfer may be via any of the device networks implemented on the FI such as: Direct Address, Virtual Bus, Lazy Susan, LI Broadcast. In any case, the LIU must recognize that it must accept data by analyzing the packet header, and then transferring the data into one of its appropriate receive buffers. This category includes the command/response messages between the FI Manager and the devices. In addition, a message from the FI Manager directly to the LIU, containing Virtual Bus or Lazy Susan access sequence information, will also fall into this category.

5.1.1 Local intraconnect data transfer. The LIU provides an interface between the user device (SAU) and the LI bus. The data transfer between the device and the LIU, and between the LIU and the LI bus will be discussed individually in this section. The two interfaces are shown in Figure 5-4.

5.1.1.1 Device/LIU data transfer. At the LIU-device interface, the LIU controls the transfer of data to and from the device (SAU) in a DMA fashion according to the protocol defined by the FI Interface Standard. The transfer rate, data block size and word length are defined by the interfacing device (SAU), but are limited as discussed herein. The data format is constructed to be flexible in order to service DTEs with various word sizes, machine speeds, and storage capacity. A maximum word size of 18 bits was chosen because it accommodates the majority of the data machines identified in Section 2.3.2.1. The format is constructed on a folded 9-bit word basis so machines with nine or fewer bits per word can fold them into an 18-bit word for efficient data packing. Data block sizes from 1 to 1024 words are required to provide message transfer capacity convenient to the majority of the machines to be served. The data transfer rate is determined by the speed of the device up to a maximum of 10 Mw/s.

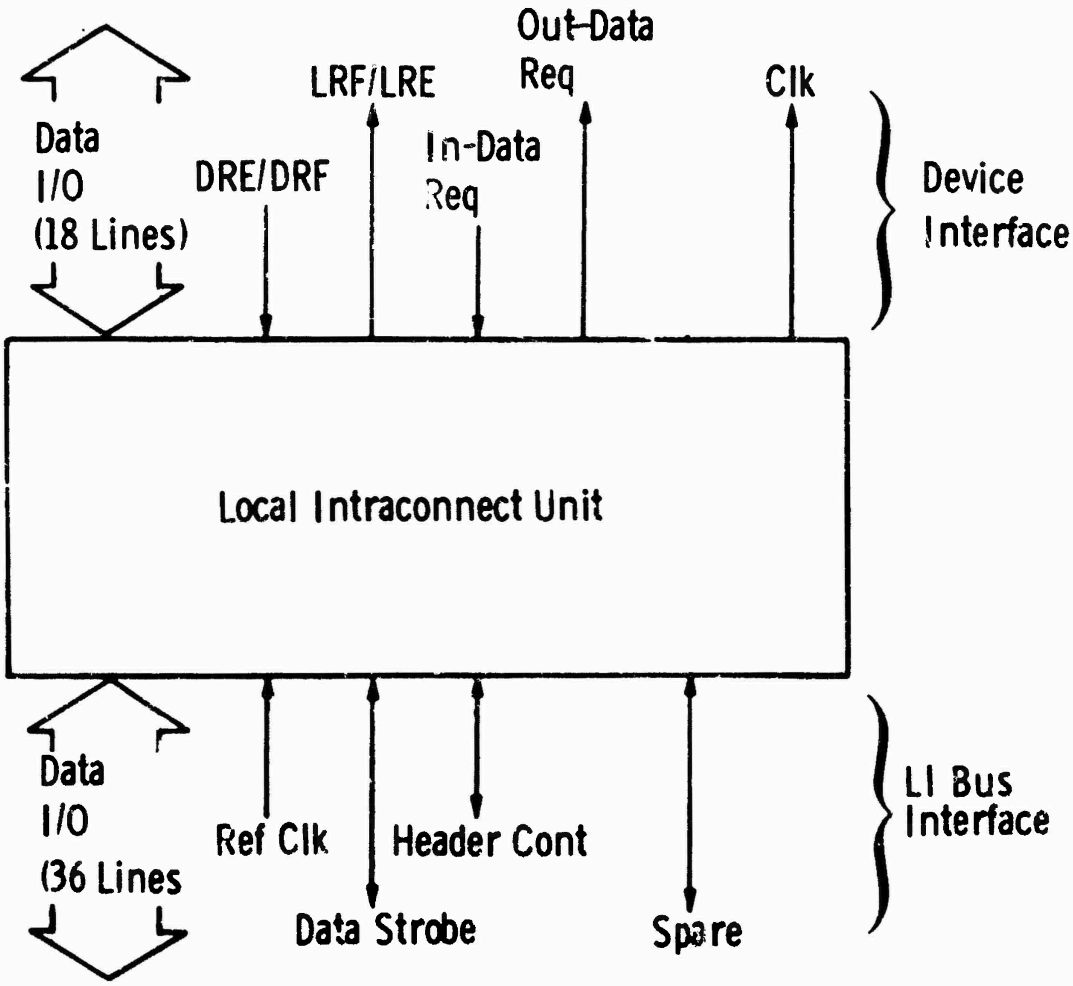


Figure 5-4. Local intraconnect interfaces.

The FI Interface Standard sets rigid constraints on data transfer protocol, device header format, maximum block size and transfer rate, signal description, etc. The FI Interface Standard is detailed in Section 6.0. The rigidity of the Interface Standard allows a single LIU to service all device types interfacing the FI which meet the interface standard. This places the burden of compatibility on the devices interfacing the FI, rather than forcing the LIU to be compatible with the hundreds of devices serviced by the FI. The approach eliminates a requirement for a number of unique LIU designs, requiring individual programming to achieve compatibility with any one of a myriad of user devices. Also, no significant burden is placed on user devices, since new device designs could be built with an FI-compatible interface as an option. FI interface cards could also be built for existing devices. SAUs will be provided for the devices incompatible with the FI interface. Section 6.0 gives several examples of simple microprocessor controlled circuits, which provide FI interface compatibility with a large number of the ADP equipment listed in Section 2.3.2.1 identified for service by the FI.

The device/LIU data transfer protocols will not be discussed in this section since it is detailed in 6.0. The data transfer protocols at each level in the FI system are described in Section 5.3.3.2.

5.1.1.2 LIU/LI bus data transfer. Data traffic on the LI bus is controlled by the LICU by polling its LIUs. The LICU grants temporary control of the bus to an LIU by polling it. Data is then transferred onto the LI bus under control of the polled LIU. The packet data, formatted in 36-bit words, is transferred onto the LI bus in a DMA fashion at a fixed rate defined by the LI timing source. The initial transfer rate of the LI bus is 5 Mw/s, but the requirement to increase to 10 Mw/s in the future within a change in line driver/receivers has been defined as a system requirement. Therefore, the initial LIU development must include the internal ability to transfer data between itself and the LI bus at a 10 Mw/s rate. The 18-bit word in the device data block is folded in the LIU into a 36-bit word for LI bus transmission. Therefore, the 1024 word maximum size of the device data block limits the LI bus data-block size to 512 words maximum.

A detailed description of the LI bus packet format and data transfer protocol is included in Section 5.3.3.2.

5.1.2 LI bus I/O interface. The two areas of the LI bus I/O character- istics analyzed in this study were the transmission medium and the bus signal format and timing. The LI bus data transmission protocols are detailed in section 5.3.3.2.

5.1.2.1 LI bus signal format and timing. Format and timing relationships of the LI bus signals are shown in Figure 5-5. The 36-bit data field has a network header, data block, and trailer. The header block consists of eight words, with each word having four groups of 9 bits each. The 9 bits are 1-parity bit and an 8-bit transmission control information byte. The Network header, data block, and trailer are detailed in Section 5.3.3.2. The header contains such information as message block sync, message type, diagnostic messages, parity check codes, and general control information. The data block varies from 1 to 512 words, depending on the length of the device message. Eighteen to thirty-six-bit mapping in the LIU dictates that a data block length on the LI bus be equal to one-half the length of the message from the device to the LIU. There are two trailer words. The first word contains vertical block-parity check bits and the second contains End-of-Message (EOM) and end-of-transmission information.

The Reference Clock signal is a service clock for use by LIUs in processing bus data and transferring data onto the bus. The clock frequency is the same as the bus data rate. It is generated by a reference oscillator in the LICU and is provided as a system clock reference for the LI bus.

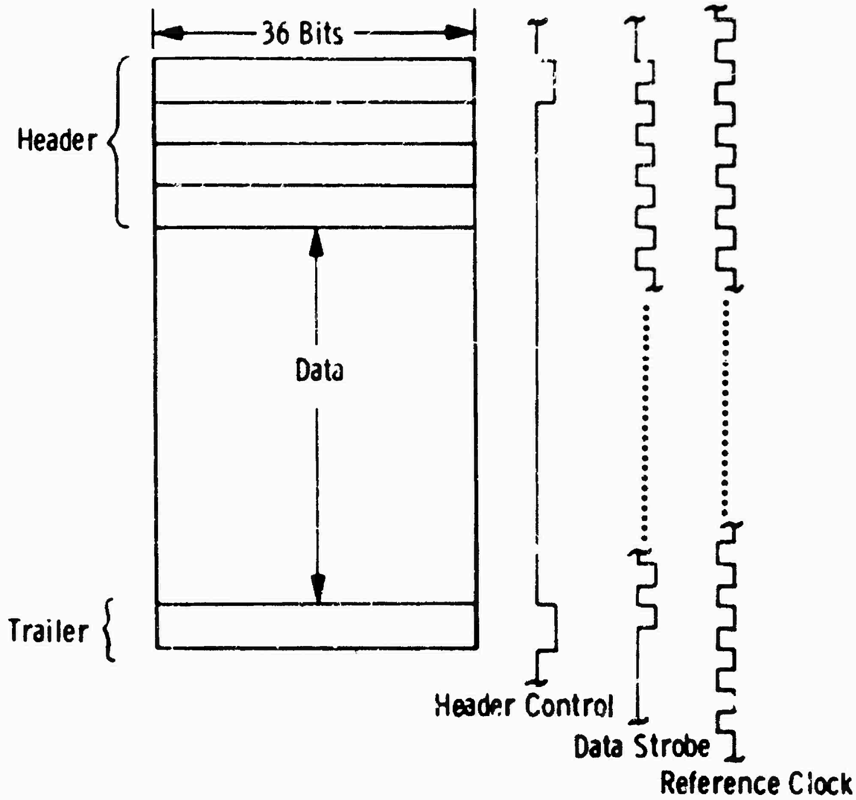


Figure 5-5. LIU/LI bus interface signals.

The Data Strobe (DS) signal is generated by the LIU or LICU transferring data onto the LI bus. The signal is delayed 180o out from the leading edge of the data word as it is strobed onto the bus by the transmitting LIU or LICU. The DS provides a 50 percent sampling edge to reduce probability of data detector errors. One DS pulse is transmitted onto the bus for each data word transmission. The line is inactive when no data is being transmitted. The DS signal is transmitted by the LIU or LICU transmitting data onto the bus to minimize the clock/data skew. If the DS were not provided, the Reference Clock would be required to strobe data into the LIU. This presents a skewing problem between clock and data due to the differential in transit time delay when the clock is generated by equipment in a different location on the bus than the equipment generating the data. The worst-case clock/data skew would occur when an LIU at the farthest end of the bus from the LICU is the data generator. Assuming that the propagation delay over the bus is 1.5 nanoseconds per foot, the clock/data skew at an LIU on either end of a 300-foot bus is 450 nanoseconds, or 4.5 word periods at 10 Mw/s. The DS Signal eliminates this problem. The DS/data skew should be less than 5.0 nanoseconds, since both signal path lengths are always equal.

The results of the flat ribbon cable tests, discussed in Sections 5.1.3 and Appendix C, indicate a significant clock and DS signal jitter accumulation, greater than 50% of the data period, when the LI is operating at 10 Mw/s over 300 feet of cable. The most obvious solution to this problem is to re- duce the clock and DS signal to one-half the data rate by delaying the signal 90° with respect to the data, and using both transition edges of the DS sig- nal to strobe the data into memory. The reference clock signal transitions must be used to multiply the clock frequency back up to that of the data rate.

The Header Control (HC) signal is generated by the transmitting LIU. It provides a sync pulse in parallel with the first header word which contains the start of message (SOM) code and another sync pulse in parallel with the last trailer word, which contains the end of message (EOM) code, of each packet.

Packets are transmitted asynchronously on the LI, requiring the LIUs to resync on each packet. Without the header control pulses, the sync pattern recognizer would be required to remain in the scan mode throughout the message block and would be vulnerable to recognition of false SOM or EOM codes in ran- dom data. With reasonable sync code lengths, the mean time to recognition of false sync would be too short for reliable data transmission. The mean time to false recognition of an 8-bit sync code in random data is only 2^{-8}, or one in 256 words. By identifying the sync position, the HC pulse eliminates the need to scan the message body, which eliminates the possibility of false detection of SOM and EOM. Proper synchronization is then dependent only upon the detection of the sync pattern in the presence of bit errors. The bit error rate on the LI is expected to be 1×10^{-6} or better. Under these conditions, the simplest detection method, that of detecting the pattern allowing no erors, produces a probability of error, $P_E(0)$, of 8×10^{-8} which implies a mean-time-to-loss of block sync (and therefore the loss of the packet of approximately 0.7 hours assuming a rate of 5×10^3 packets per second. This can be improved considerably by allowing errors in the detection of the pattern. For instance, if one bit error is allowed in the detection of the 8-bit sync pattern, the probability of packet sync loss $P_E(A)$, decreases to 5.6×10^{-15} and the mean-time-to-loss of a packet, assuming 5×10^3 messages per second, increases to approximately 1147 years. The probability of error in the 8-bit pattern is calculated by the binominal probability ex- pression.

$$P_E(K) = (n)\ p^K\ (1-p)^{n-K}$$

where: K is the number of errors occuring in the sync pattern,

n is the number of bits in the sync pattern,
p is the probability of error,
for $P_E\ (0)_1,\ K = 0$
and $P_E\ (A) = P_E\ (2 \leq K \leq 8) = \sum P_E(K)$

5.1.2.2 LI transmission media. The LI bus provides the transmission path between the LIU's and the LICU via a forty twisted-pair flat ribbon cable (FRC). As illustrated in Figure 5-5, 39 of the signal lines are presently used for data, control, and a reference clock, leaving one spare line for future requirements. Thirty-six of the lines are dedicated to bidirectional data transmission, two bidirectional control lines (DS and HC), and the unidirectional reference clock line which originates in the LICU and terminates at each LIU.

The FRC must be capable of satisfying certain transmission criteria if it is to prove a viable candidate for the LI transmidia media. This criteria is listed below.

a. 40 Twisted pairs per cable;
b. Greater than 300 ft. cable length;
c. Up to 64 LIUs maximum, distributed over the of length cable in a party line manner;
d. 36-bit parallel 10 Mw/s transmission rate;
e. Bidirectional data transmission; and
f. Better than 1×10^{-8} BER.

Manufacturer specifications indicated that FRC technology would satisfy the LI transmission requirements. However, the specifications were not definitive enough to assure the feasibility of applying FRC technology to LI bus transmission. Therefore, to determine if the use of FRC is feasible and to determine it's transmission parameters, a partial configuration of this data bus was constructed and tested in the laboratory. The test report is contained in Appendix C. A summary of the test and test results are discussed below.

Figure 5-6 illustrates the laboratory bus on which the transmission tests were run. The bus consisted of four 100-foot sections of 20 pair Twist'N'Flat™ planar cable manufactured by Spectra-Strip Corporation. The 20 pair cable consists of stranded 28 AWG round conductors insulated with colorcoded PVC, twisted into pairs and laminated between layers of PVC film to form a planar cable. Twisted pair sections 18 inches long alternate with 2 inch flat sections in which the conductors are laminated in parallel on 0.05 inch centers. The flat sections are used as termination points for Insulation Displacement Connectors (IDCs).

Twenty-one driver/receiver pairs were connected to the main 400 foot cable, at 20 foot intervals, via 6 foot Twist'N'Flat cable stubs. IDCs were used to connect the 100 foot cable sections together and the stubs to the cables. Four separate power supplies were used for the driver/receiver pairs and each one returned to a single point ground to simulate individual LIU power supplies connected to a single port ground in a shelter. Only the 400 foot cable was terminated at both ends, the stubs were left unterminated.

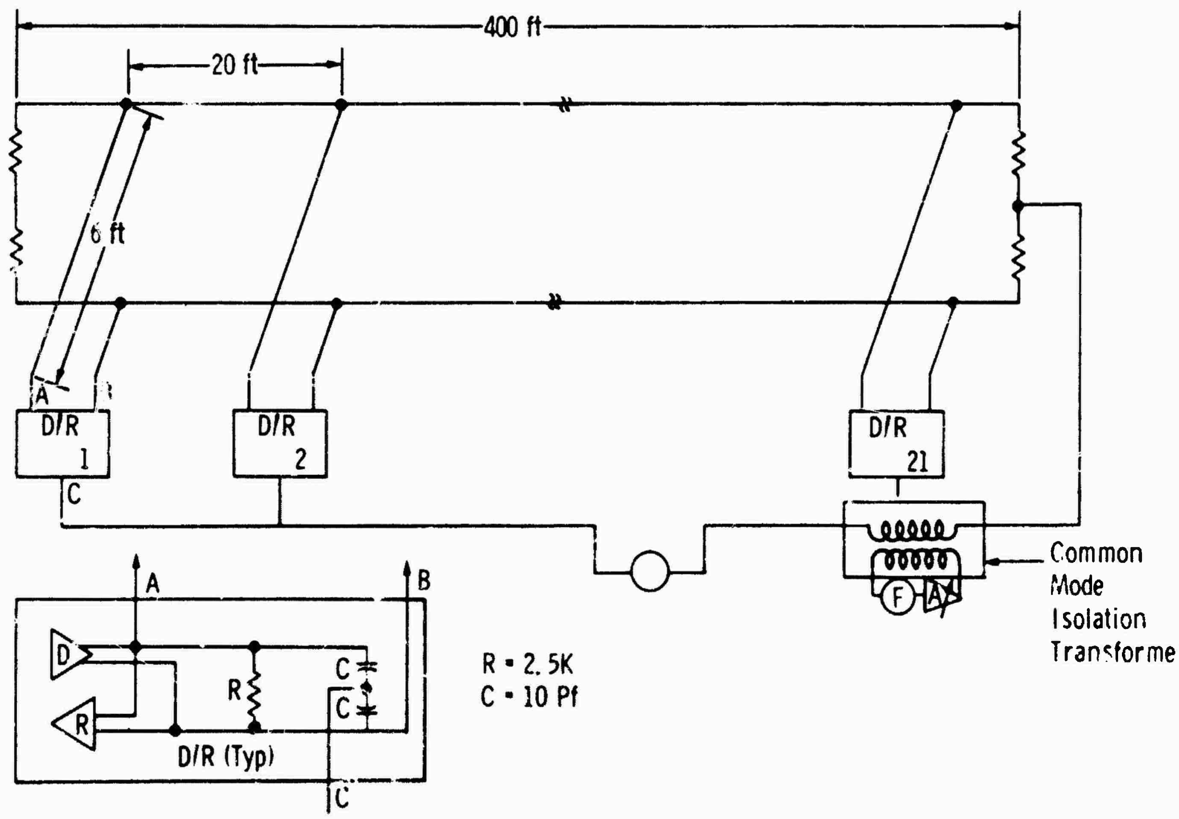


Figure 5-6. Cable transmission test.

Dual differential line drivers with 3-state outputs were used since only one driver is allowed to transmit at a time on the LI bus. Resistor/Capacitor circuits with impedance equivalent to two driver/receiver pairs were added to the inputs of 21 receivers to simulate an additional 42 driver/receiver pairs dispursed over the length of the cable.

Transmission quality was measured by passing a pseudo-random data stream of length 2^{15} down one 400 foot twisted pair. The control variables of the test were; data rate, transmission distance, and common mode noise. The received data stream was monitored at specific points on the cable, while the data rate was increased. The eye pattern of the data stream out of the receiver was observed to determine the data rates at the points of closure of the eye. The maximum data rate considered acceptable at any length down the cable was at the point where the eye pattern had begun its closure but was still very distinguishable. The maximum acceptable data rates determined in the tests at 300 feet and 340 feet down the 400 foot cable are listed below.

No Common-Mode Noise:
9.5 Mb/s @ 340 feet
10 Mb/s @ 300 feet

Common-Mode Noise (6V @ 1KHz):
8 Mb/s @ 340 feet
10 Mb/s @ 300 feet

Cross talk tests were conducted with both 2 adjacent channels driven and four adjacent channels driven. The adjacent channels were driven with ± 3 volts at 10 Mb/s. The results of the crosstalk tests listed below were approximately the same for both 2 and 4 adjacent channels driven:

Near-End Crosstalk < 100 mv
Far-End Crosstalk < 80 mv

The tests were not all inclusive, and more tests should be conducted, expecially in the area of common mode noise and crosstalk. However, the tests give a good indication that the Twist'N'Flat cable can support a 10 Mb/s transmission rate over 300 feet of LI cable with up to 64 LIUs attached, with greater than 6 volts of common mode noise. The general conclusion of the tests is that it is feasible to construct the LI bus with twisted-pair conductor cable which is available off-the-shelf.

5.1.3 Shelter intraconnect unit. In certain TAF centers, some shelters do not support enough intra or intershelter traffic to warrant the use of either an LI or an EI link for that shelter. Other centers, listed in Table 2-11, such as the TWAC or ASRT do not support enough traffic in the whole center to warrant an FI. A special interface unit (SIU) will be developed to provide the devices in these shelters access to the FI via an LI bus in another shelter within the center or another center which has both an LI and an EI link. SIUs which provide three different interfacing functions were studied in Task III. The SIU function illustrated in Figure 5-7 was the one chosen as the most versatile. In this configuration, each device (SAU) in a remote shelter, i.e., one that is remote from an LI bus, is provided with an SIU. The function of the SIU is to interface the device (SAU) on one side and provide an external shelter transmission link interface on the other side. The external transmission media will most likely be a fiber optic (FO) link for the same security reasons as fiber optic transmission is used for the EI system (see Section 5.2). An SIU performing only line and FO modem functions can be kept quite simple, if it is not required to do either the more complex SIU or LIU functions. In the Local shelter, the SIU to LIU (SAU) interface appears to them as if the device were local.

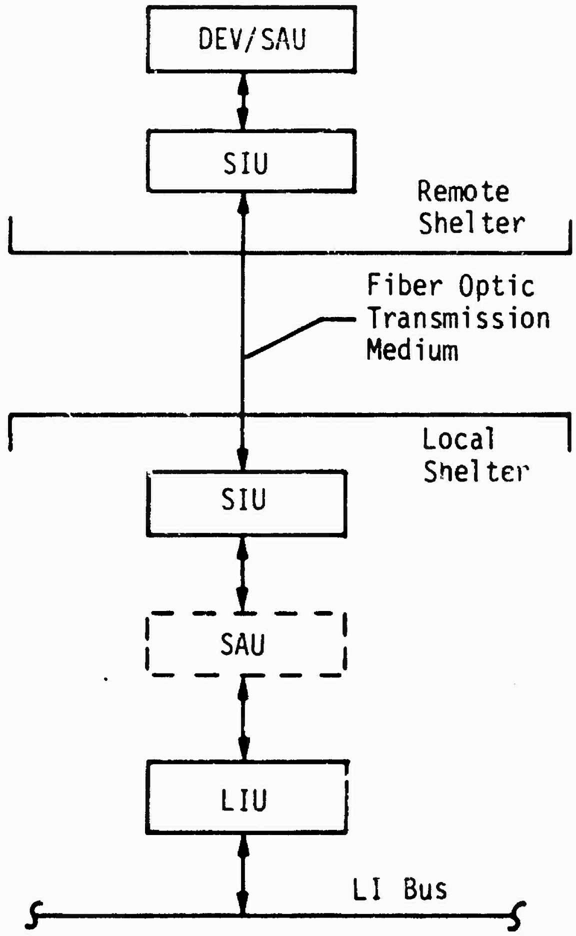


Figure 5-7. SIU operation in FI.

This type of SIU can prove to be a very economical tool of the FI in TAF centers where the low density traffic warrants their use. This fact is demonstrated in Section 7.1.6.

A second approach to the definition of an SIU is illustrated in Figure 5-8. Here the SIU provides the extension of the LI bus in a local shelter to a number of devices (SAU) in a remote shelter. In this approach, LIUs are used in the remote shelter, and neither the LIU nor the devices (SAUs) will recognize that the actual LI bus is resident in another shelter. The increase in response delays caused by the transit time in the FO transmission media plus the internal delay in the SAUs. The additional delay encountered in the fiber optic transmission link (5.1 nanoseconds/meter) could cause a round trip delay over 8 km of cable of 81.6 microseconds. If this delay is acceptable, then this approach could be used.

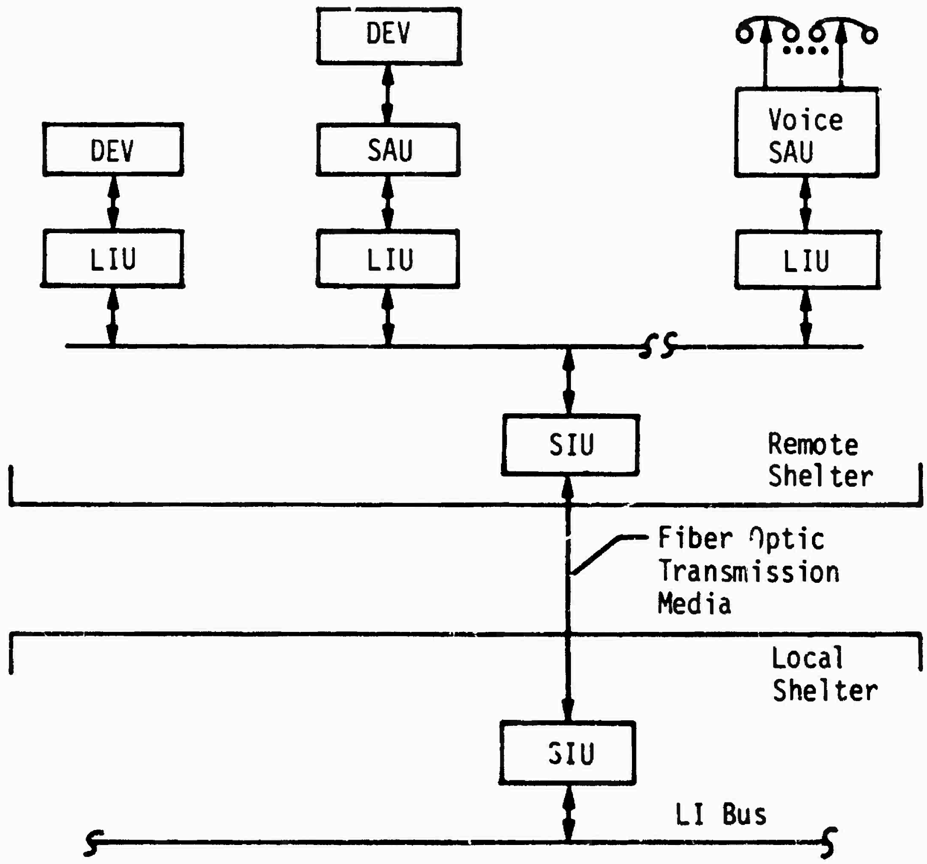


Figure 5-8. SIU extending LI bus.

The third approach uses the SIU to provide the interface between the LI bus and the external transmission media in the Local Shelter, and between the device (SAU) and the external transmission media in the remote shelter. This approach incorporates the LIU function in the SIU and by doing so, unduely complicates the SIU. Since relatively large quantities of LIUs will be available at the centers, no advantage is gained by placing the LIU function in the SIU. THerefore, this approach was discarded.

5.2 External Intraconnect (EI).

The EI is the interconnect facility that allows user devices in different shelters to communicate with one another. The EI, as illustrated in Figure 5-9, consists of the EICU, a switched-active transponder, an EIU for every point of the star, and a full-duplex fiber optic transmission medium between each EIU and the transponder. Two types of transmission service are supported over the EI; Digital TDMA Transmission and high-speed analog.

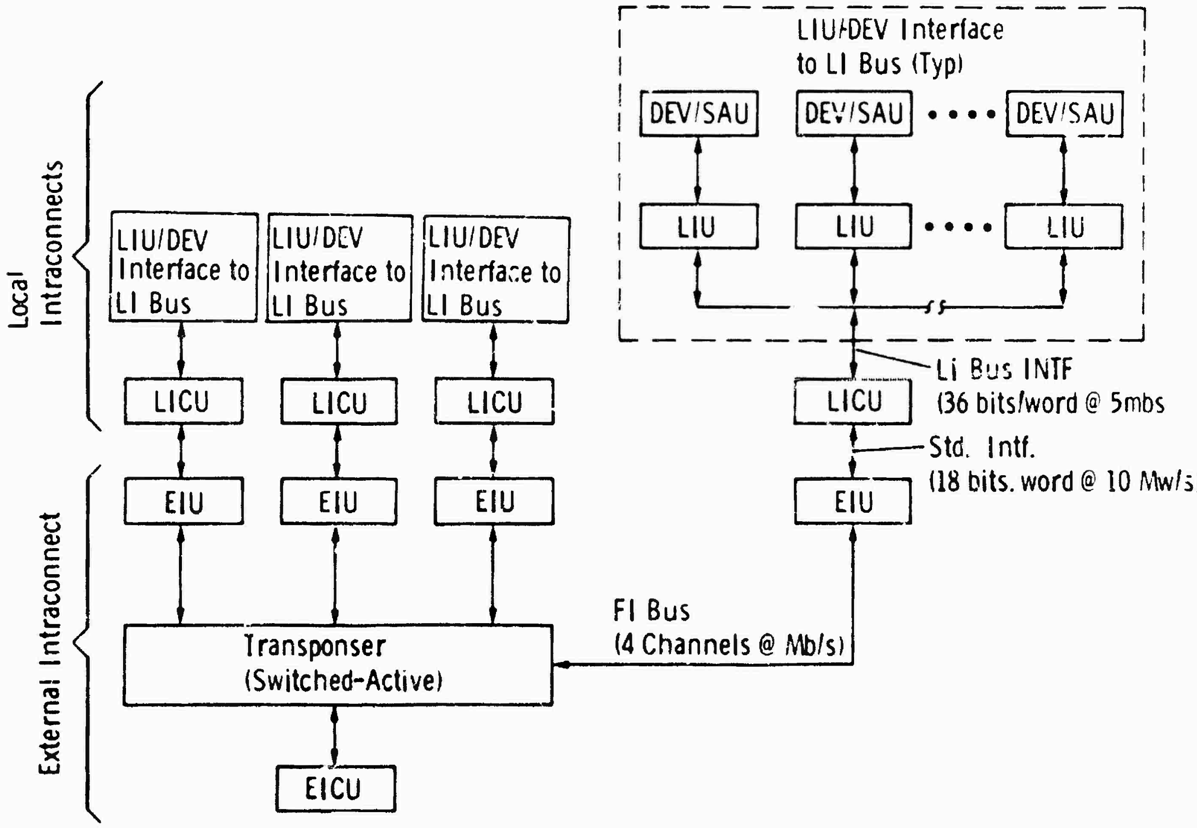


Figure 5-9. EI interface with the LI.

5.2.1 Digital TDMA transmission. The Digital TDMA Transmission section of the EI is used to transfer data packets generated in the LIUs between LIs in different shelters. The EI transmission system consists of two links between the transponder and each shelter: One up-link from the shelter to the transponder, and one down-link from the transponder to the shelter as shown in Figure 5-10. The first level of polling for transmission of data between shelters is performed by the EICU, which polls one shelter at a time in the specific sequence defined by the polling algorithm. This is accomplished by transmitting the selected shelter's polling data in an encrypted packet that includes its address over every downlink in the star. Upon recognition of its address and polling information, the polled EIU then transmits its encrypted response packet over the uplink to the transponder. The transponder retransmits the shelter's response packet over the EI downlinks to every EIU in the system. Each EIU, therefore, receives all transmissions from every source on the EI, but responds only to those packets addressed to it.

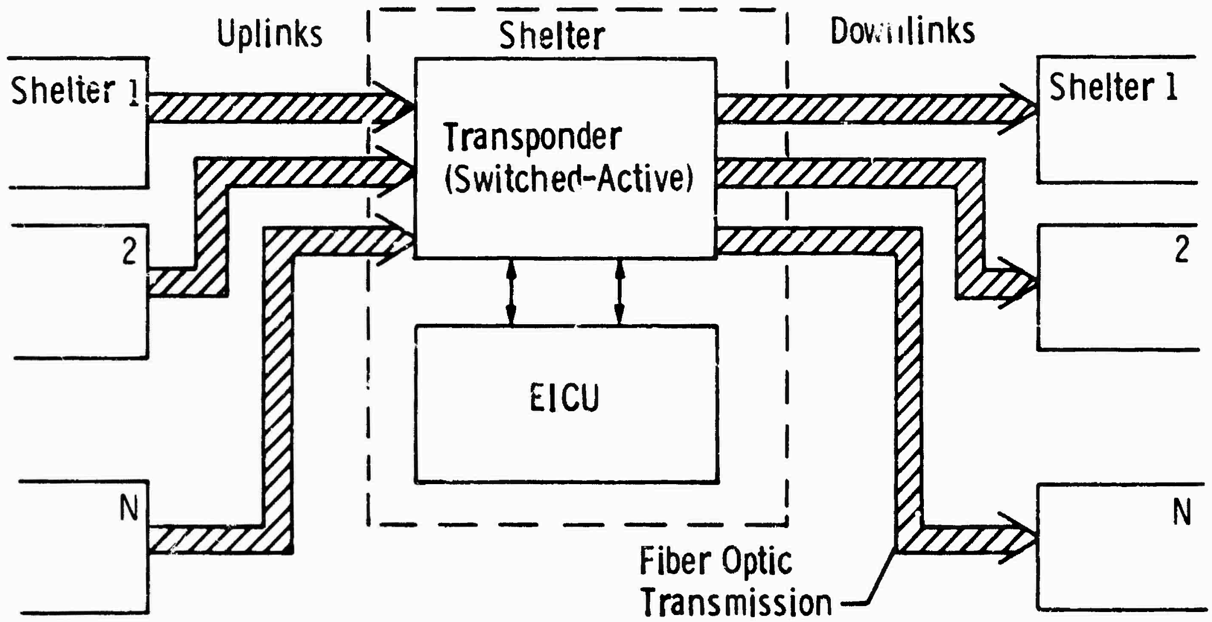


Figure 5-10. Full-duplex EI transmission.

The polling mechanism in the EICU must be designed so the intershelter polling algorithm is dynamically alterable to suit the data traffic requirements of a particular center. This allows for the evolution from a very simple, fixed-sequence polling scheme to accommodate the static-dedicated nature of the communications users in SCC-1, -2, and -3, to a sophisticated priority-polling algorithm when serving a mixture of ADP and communications users on a dynamically dedicated, priority basis in SCC-4B.

Data packets received from the LICU for EI transmission are encyphered off-line in the EIU and multiplexed into a word and bit serial TDM/TDM stream, then transmitted in an SDM fashion to the transponder over its four parallel 50 Mb/S channel uplink. The uplink consists of six optical fibers: Four for the four 50 Mb/s data channels, one 50 Mhz byte clock, and one 5 Mhz word clock. Only one EIU transmits a data packet over its uplink during any specific period of time. All other EIUs transmit a long pseudorandom sequence on their uplinks, such that each uplink appears as continuous 200 Mb/s transmission. A typical linkmessage transmission sequence is illustrated in Figure 5-11. The start of transmission (SOT) code, cypher-text packet, PRS generation are discussed in detail in Volume II. Continuous transmission on the uplink is always quantisized into thirty-six byte words and identified by the bit and word clock. The data/clock relationship is illustrated in Figure 5-12. The multiplex format of the data (cypher text packet, SOT code, or PRS) that is transmitted in a commutational byte sequence over parallel channels 1 thru 4, can be seen to be word sequential TDM, byte sequential TDM, byte parallel (byte = bits: 1-4, 5-8, 9-12, etc.) SDM. The byte clock defines the bit periods for each of the four channels and the word clock defines the start of each word. The PRS must be also grouped into discrete quantums of 36-bit words, so it won't define the transition from the idle PRS to the start of a data packet transmission.

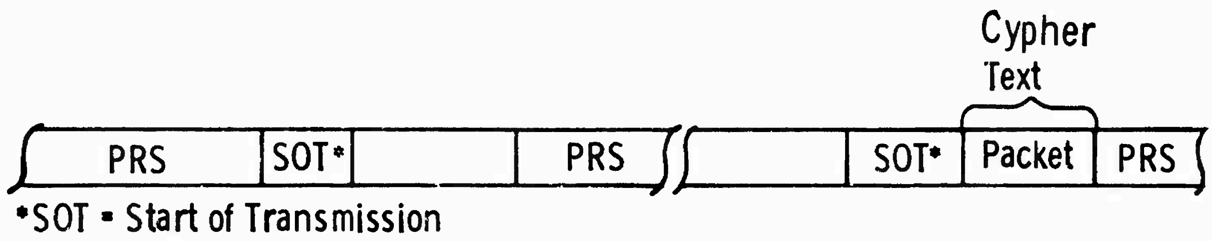


Figure 5-11. Typical up-link message transmission sequence.

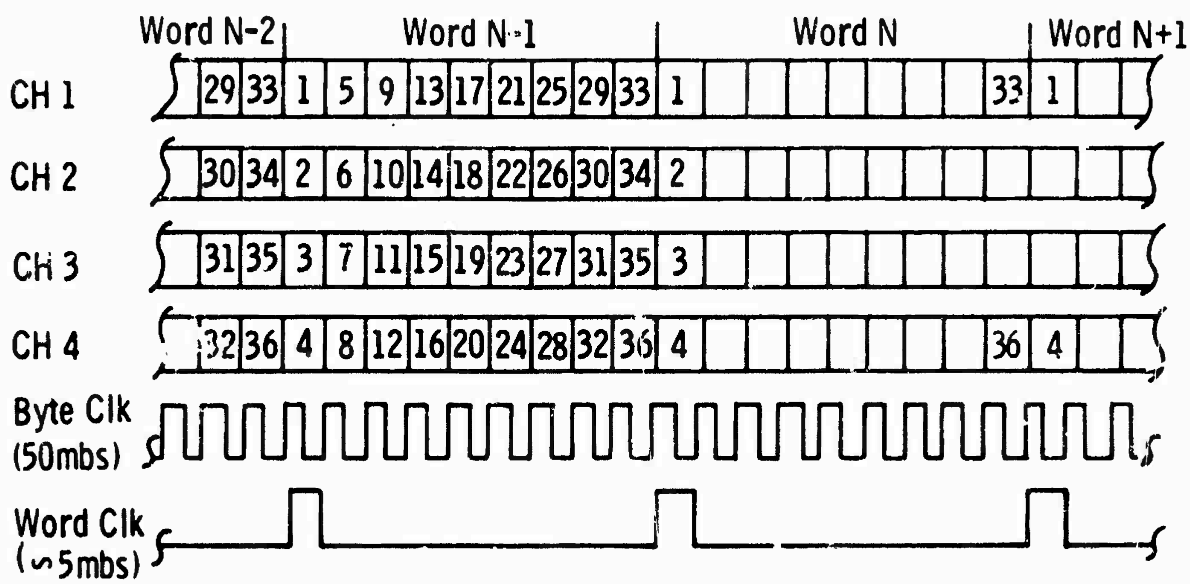


Figure 5-12. Up-link signals.

The transponder, operating under control of the EICU, switches its commutator to the uplink of the EIU selected to transmit the next packet. The uplink data is transferred into a resync buffer by the uplink byte and word clock. The EICU/Transponder byte and word clock are used to transfer the data out of the buffer and into the optical transmitters driving the downlinks to each of the EIUs on the EI. Each downlink consists of seven optical fibers: Four for the four 50 Mb/s data channels and 50 Mhz byte clock, one 5 Mhz word clock, and an additional fiber used by the EICU to inform all EIU that it is resynchronizing the SOT sequence. The data, byte and word clock signals are the same as illustrated in Figure 5-12. The special SOT sequence resynchronizing signal is described in Volume II. The downlink packet transision sequence looks similar to the sequence in Figure 5-11 except that the cypher text packets are much closer together since the downlinks contain poll packets plus all data packets transmitted from every EIU on the EI.

The EIU scans the random data on its downlink for the SOT code. When it recognizes the SOT, it strobes the cypher text packet into a receive buffer, resynchronizes the KG receive section, decyphers the header, and determines if the packet is destined for it. If the packet is not destined for the EIU, it discards the packet. If the packet is destined for the EIU, it determines what action it must take, and responds either by passing the packet on to the LI or by transmitting a response packet over the EI. Types of messages and responses will be discussed in a later section.

All up and downlinks operate at the same continuous bit transmission rate of 200 Mb/s. However, the uplink message rate will differ from shelter to shelter and is dependent on the shelter's EI message traffic requirement. Some of the uplinks are anticipated to have almost negligable message traffic (less than one message per second) while others may support relatively high message rates of greater than one-thousand messages per second. The downlink message rate is dependent on the composite of the center's intershelter traffic and will, therefore, have a much higher message traffic density than the uplink.

5.2.2 Analog transmission. The analog transmission section of the EI is used to transfer unidirectional wideband analog signals, such as radar and TV video between shelters on the EI. It consists of simplex links, between the transponder and the shelters engaged in the EI analog transmission. The analog signals will be Frequency Division Multiplexed (FDM) on a single carrier for transmittal over a dedicated fiber in the multifiber optical cable. Carrier modulation may be either in the electrical domain, using a standard FM modulator whose output moves the optical source, or direct FDM of the optical signal using either an acoustio-optical or electro-optical modulator.

The transponder provides the dedicated patching function to r the analog signal from the source shelter to the destination shelter. In most cases the optical signal will be regenerated in the transponder.

The fiber optic components used on the analog link and the transmission analysis are described in Section 5.2.4.3.

5.2.3 External Internal Unit. The External Intraconnect Unit (EIU) provides the interface between the LI bus and the EI; just as the LIU provides the interface between devices and the LI. Figure 5-13 illustrates the EIU interface with the LI (LICU), and with the EI bus. At the EIU-LICU interface, the EIU controls the transfer of data to/from the LICU in accordance with the protocol defined for this interface. The LICU/EIU interface has been preliminarily defined by RADC as being the same signal interface and data transfer protocol as the LIU Standard Interface. At the EIU-EI bus interface, the EIU transfers data to/from the bus under the control of the EICU by responding to a poll or query, or by accepting data destined for its resident LI. The EIU accomplishes its task by: Recognizing the destination address of the message as being its own; or by recognizing the message type as one to be automatically accepted for transmission to it's resident LI. The EIU rejects all other messages. If the EIU recognizes a poll message with its address as the destination address, it always responds with either: A message from its resident LI that is destined for another LI if on exists in its buffer; or if not, it responds with an idle message.

Figure 5-14 illustrates a functional block diagram of the EIU. The EIU performs four basic functions necessary for flexible and efficient operation of the EI:

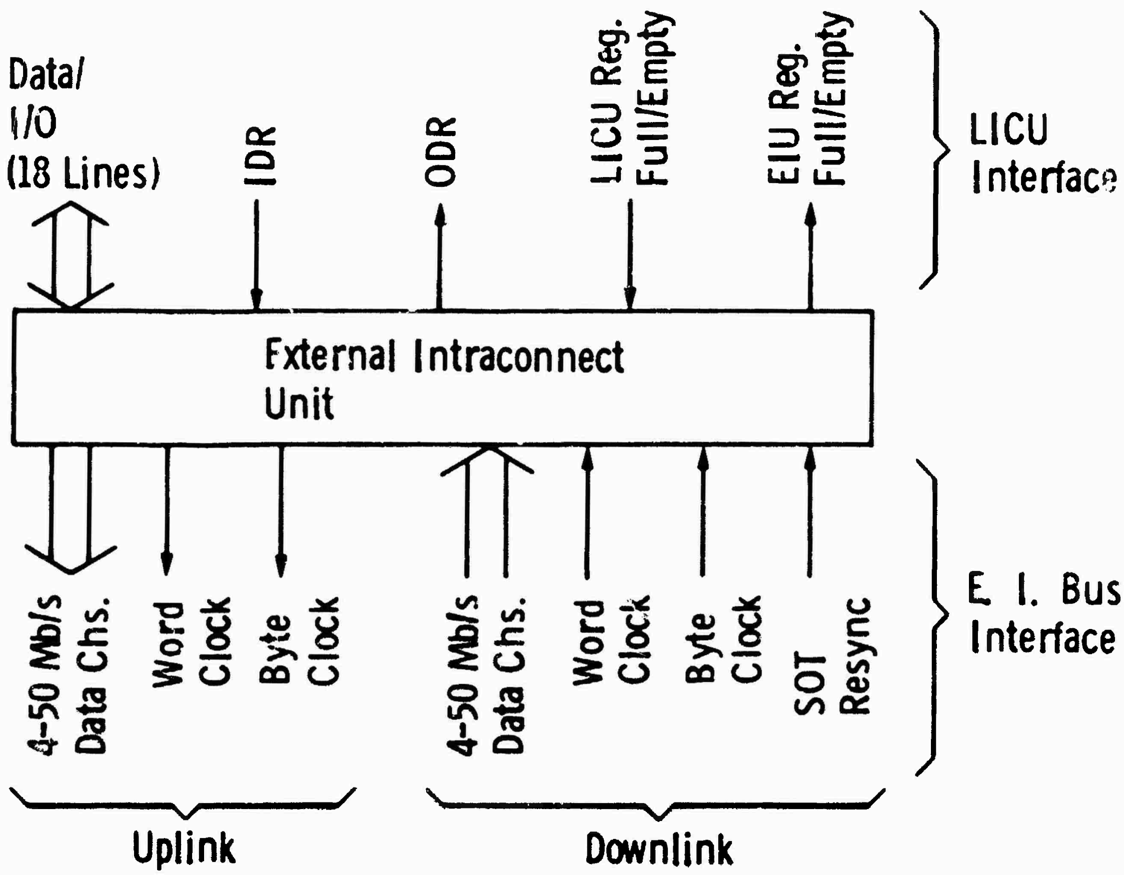


Figure 5-13. External intraconnect unit interfaces.

a. Interface Transformation. Transforms the LI external interface signals (18-bit words at 10 Mw/s) to and from the EI bus signals (four 50 Mb/s fiber optic channels). The LICU/EIU interface is fixed, as discussed previously. However, as far as EIU operation is concerned, its design can be made flexible to interface with various transmission media and various transmission rates. This could be accomplished by a simple programming step defining the number of EI channels, and changing the EI bus interface modems for compatibility with the transmission medium.

b. Off-Line encyphering/decyphering. The shelter EI message traffic is estimated to be much less, in most cases, than the 200 Mb/s EI transmission media. Since only the packets going to and from the concerned shelter it need by encyphered or fully decyphered, the shelters actual message traffic may be encyphered/decyphered offline by relatively slow KGs. This will obliviate the need for multiple, high speed KG's generally required to minimize EIU response times and eliminate the possibility of message buffer overflow, or the need for high-density buffers.

c. Fast recognition and response to EI messages. The EI message transmission capacity and throughput delay are heavily dependent on the time required by the EIU to both: Determine if each message on the EI downlink is destined for it; and, if required, output a response message with minimal time delay.
d. Message filtering. All messages not destined for the EIU or resident LI must be filtered out to reduce the size of the EIUs EI receive buffers, minimize throughput delay, and reduce the KG decyphering speed requirement.

The EIU, (Fig. 5-14), is comprised of the following blocks:

a. LICU interface (driver/receiver and control) is the same as the LIU/Device interface circuits;
b. Microprocessor and program memory controls the initialization and programming of the major EIU functions and then allows the units to perform the high-speed data transfer and processing independently;
c. Transmit section strobes in the data packets from the LICU, encrypts them and stores them until it is polled, and then transfers the data packets onto the LI bus uplink. The Transmit section is described in Section 5.2.3.1.
d. Receive section accepts all packets transmitted on its downlink, filters out all packets not destined for it, and decyphers the packets destined for its resident LICU. The receive section is described in Section 5.2.3.2.
e. Optical drivers and receivers interface the EIU to the LI bus fiber optic transmission cable. The drivers and receivers are described in Section 5.2.4.2.

Part of the EIU operation is classified and appears in Volume II.

5.2.3.1 EIU transmit section. The EIU Transmit section, illustrated in Figure 5-15, operates under microprocessor control to:

a. Transfer LICU packets, destined for EI transmission, into a Plain Text (PT) buffer;
b. Encypher packets in a KG transmit unit;
c. Store encyphered packets in a Cypher Text (CT) buffer while waiting for a poll;

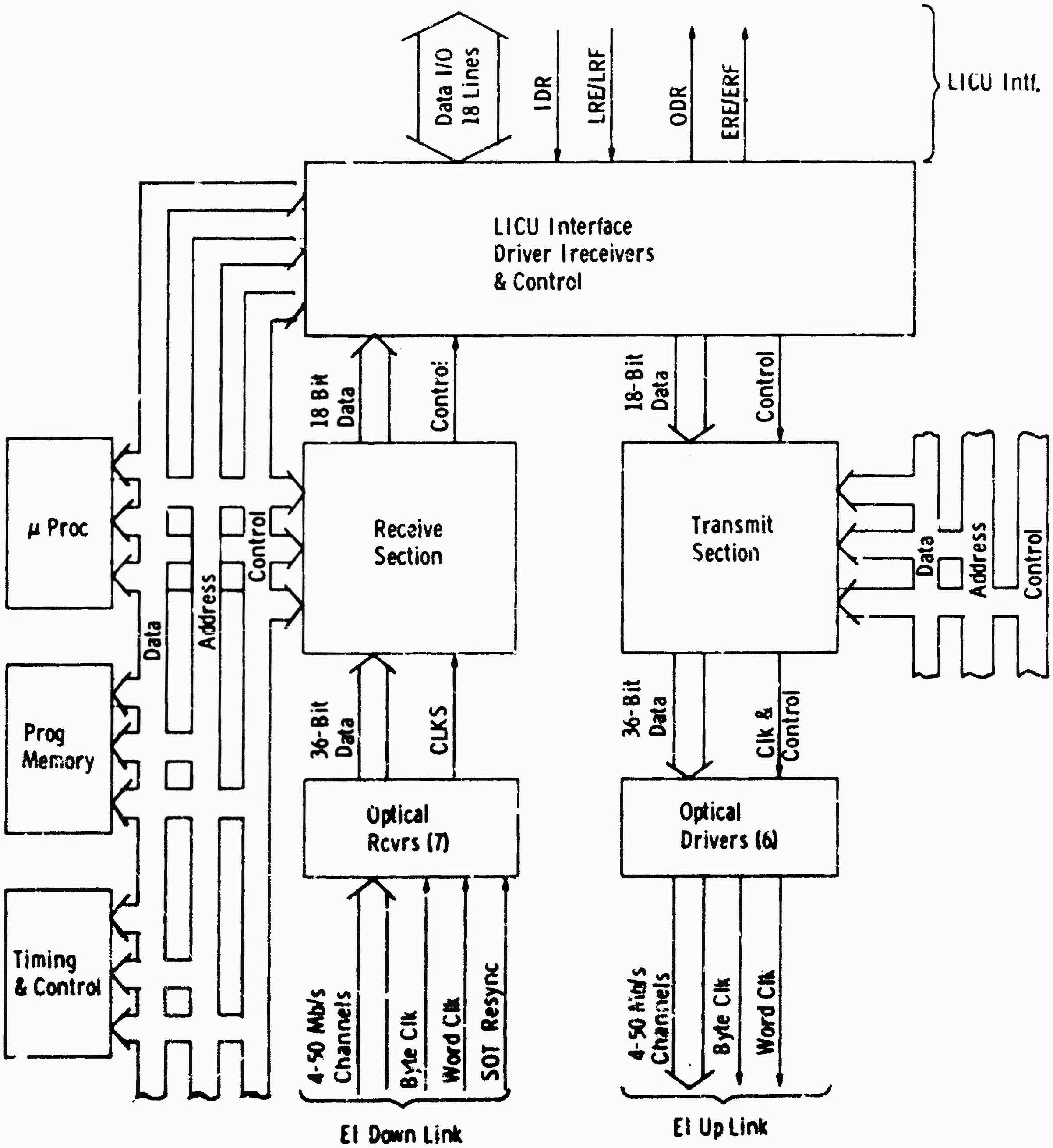


Figure 5-14. EIU block diagram.

d. When polled or queried, transfer packets from CT buffer and convert them into a format compatible with the EI transmission facility;

e. Provide a pseudo-random sequence to fill the gaps between encyphered packet transmission on its uplink; and

f. Transform the baseband signal (packet of pseudo-random sequence) to modulate the optical carriers for transmission on its uplink.

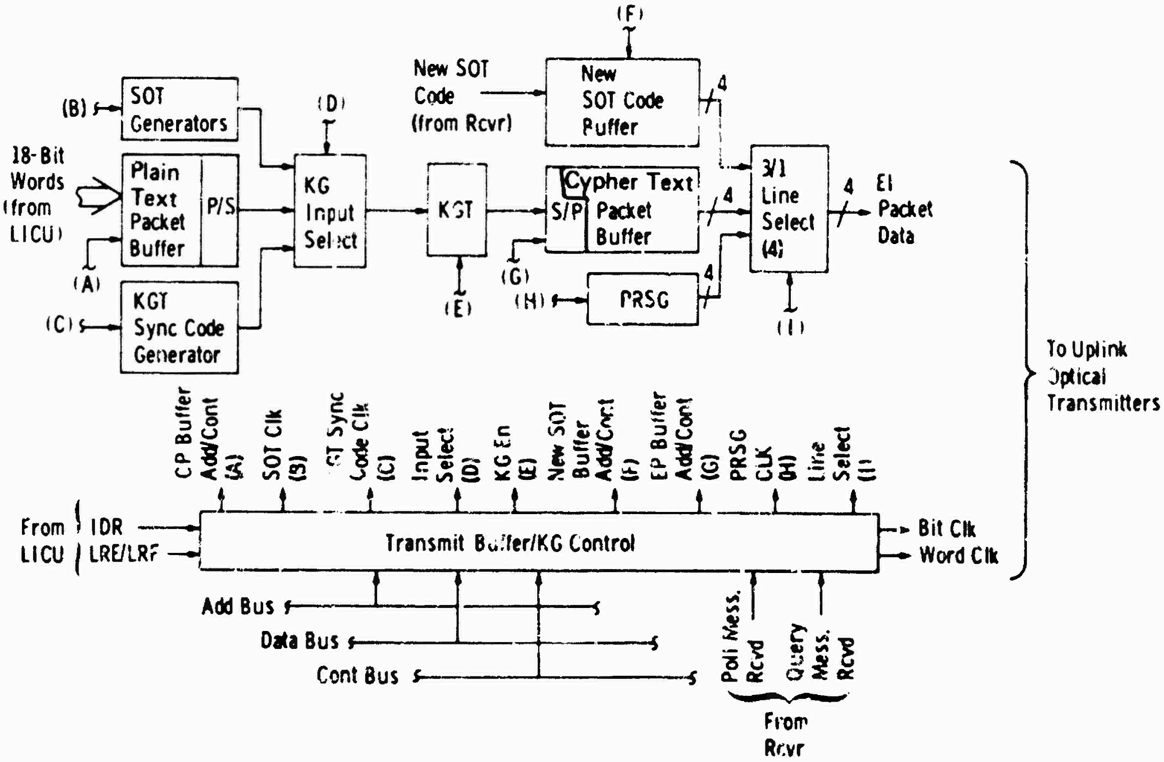


Figure 5-15. EIU transmit section.

The Transmit section, when enabled by the microprocessor, controls DMA transfer of 18-bit data from the LICU into the PT buffer. Refer to Sections 5.3.3.2 and 6.0 for a description of the data transfer protocol. Received packets are stored in the buffer until the KG transmitter (KGT) is available to encypher the packet. The KGT need operate at the packet transmission rate of the EIU only. When a new packet is to be encyphered, the KG sync code is parallel to serial converted and routed through the KGT input selector. Once the KGT is synchronized, the SOT code is routed through the selector into the KGT, immediately followed by the serialized data packet. The KGT discussed in this section is assumed to be a serial type such as the KG-4S which operates up to 20 Mb/s. The relationship of the SOT code and the packet, the KG sync scheme and the actual baseband data stream format, are classified and their descriptions are contained in the classified Volume II.

The encyphered serial packet stream is serial to parallel converted (1-to-36 bit) and loaded into the Cypher Text (CT) buffer. The packet is held in the buffer until the receive section recognizes a poll message with the EIU address and sends a Poll Message Received (PMR) signal to the Transmit section. Until the PMR signal is received, a long pseudo-random sequence is routed from the PRSG through the Line Selector out to the four optical data transmitters. The data output of the PRSG, CT buffer and the new SOT code buffer are all framed in four-bit bytes and nine-byte words. When a PMR signal is received, the new SOT code followed by the encyphered packet are passed through the selector to the transmitters. The byte and word clocks are generated in the Transmit Buffer/KG, control is routed to optical transmitters where together with the four data channels, they form the uplink data and clock transmission illustrated in Figure 5-12.

The timing and control signals for each block in the Transmit section are generated in the Transmit Buffer/KG Control block. The control block operates under control of the microprocessor, and can be programmed to allow for more than one KGT to operate in parallel if one is not adequate to accommodate the message traffic. The control block can also be programmed to allow for a variying number of data channels rather than four to provide the flexibility of interfacing with EI transmission media other than the particular fiber optic cable discussed in Section 5.2.4.2.

The Poll response packets (data or idle message) and possibly the query response packets are encyphered a priori and stored in the buffer in anticipation of a poll or query. The packet processing is performed in this manner to eliminate the sizeable response-time delay, which would be incurred if the packet encyphering and encyphered packet storage functions were performed after a poll or query message was detected.

5.2.3.2 EIU receive section. The EIU receive section, illustrated in Figure 5-16, operates under microprocessor control to:

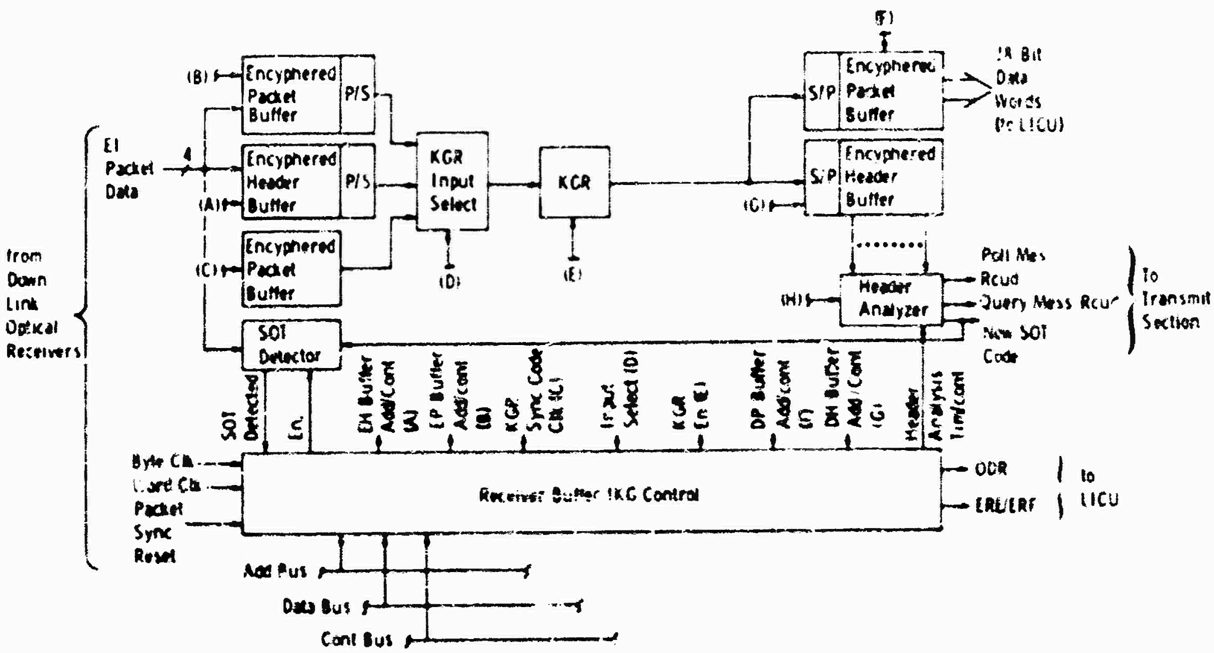


Figure 5-16. EIU receive section.

a. Transfer all EI packet headers on the downlink into a buffer;
b. Decypher and analyze each network header and determine whether to accept or discard the incoming packet;
c. Store packets intended for it or its resident LI;
d. Decypher and store all data packets destined for the local LI;
e. Transfer the decyphered data packets to the LICU; and
f. Upon detection of a poll or query message addressed to the EIU, send a poll or query response command to the transmit section.

Once the EIU is initialized by the microprocessor, the receive section monitors the EI downlink for a SOT code. The SOT code, immediately preceeding the packet, is used to identify the start of a new packet transmission. Packets are transmittted asynchronously on the down link according to a TDMA scheme. The packets are immersed in a pseudo-random digital stream used to fill gaps between packets, creating a continuous transmission. A typical up or downlink transmission is illustrated in Figure 5-17. For a complete description of the EI transmission stream and the EIU operation, refer to Volume II. When a SOT code is recognized, the encyphered packet header is transferred into the Encyphered Header (EH) buffer. The process of transferring the full packet into the Encyphered Packet (EP) buffer is also initiated.

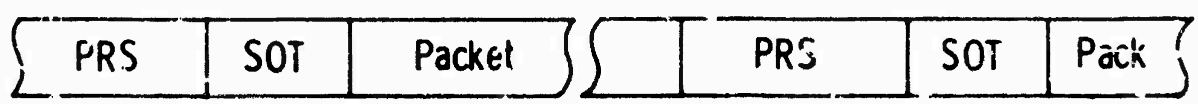


Figure 5-17. Continuous up/down-link transmission.

Immediately upon the recognition of a SOT code on the downlink, resynchronization of the KGR* is initialized, whether a data packet destined for the LI is in the process of bieng decyphered or not. Each packet being decyphered by the KGR is retained (in cypher text) in the EP buffer until the packet is fully decyphered. This protects the encyphered packet against loss if the decyphering process is terminated because a new packet header is ready to be decyphered. Header decyphering always pre-empts data packet decyphering in the interest of minimizing poll and query response time delays. Response time delays could be significantly increased if each header were put in queue in the input buffer and forced to wait for full decyphering of each EI packet received before it. This procedure would subject the EIU poll and query response times to be dependent on the EI message traffic. The process of immediately decyphering and analyzing each packet header upon its reception not only minimizes poll and query response times, but acts as a packet filter at the input to the EIU. The filtering is accomplished by allowing only data packets that the header identifies as destined for the resident LI to be stored in the EP buffer. Through packet filtering, the buffering and decyphering processes become functions only of portion of the EI traffic destined for the shelter in which the EIU resides. Without filtering, the processes are functions of the total EI traffic, which is generally of much higher density. The results of packet filtering are twofold:

a. Significant reduction in EP buffer size, and
b. Reduced decyphering load on the KGR (reduced speed requirements).

The implementation of the buffering, selection, and decyphering processes will now be described. When a SOT code is recognized, the KG sync code is routed through the KGR Input Select circuit to the KGR. If a data packet was being decyphered when the SOT code appeared, the buffer control would recognize this and cause the full cypher text packet to be retained in the EP buffer. The packet cannot be partially decyphered, i.e., if the process is prematurely terminated it must be restarted from the beginning. Once the KGR is synchronized, the cypher text header is strobed serially through the select circuit into the KGR. The header is then decyphered by the KGR, converted to parallel and stored in the decyphered header (DH) buffer. The plain-text header is then analyzed to determine the type of message received and if the message was intended for the EIU. Packets meeting one of the following three conditions are stored in the EP buffer, and decrypted and stored in the DP buffer for subsequent transmission to the LICU.

a. Poll packet directed to the EIU: Requires the EIU to respond by transmitting a poll response packet (data or idle);
b. Query packet directed to the EIU. Requires the EIU to respond by transmitting a query-response packet indicating if it has a buffer available to accept a direct address packet; and
c. Data packet destined for the EIU's resident LI.

All other packets not meeting these conditions are ignored. Also, the new SOT code is sent to the SOT detector in the receive section. The new SOT code is used to determine the next packet transmission. When poll or query packets directed at the EIU are detected, new SOT code is also sent to the transmit section.

The decyphered data packets stored in the DP buffer are transferred to the LICU in the DMA fashion according to the Interface Standard discussed in Section 6.0.

The EIU description just completed was based on the assumption that KGR processing speed is sufficient to meet both the LI/EI data traffic and also provide poll and query responses within the time required to meet the EI traffic flow requirements and data throughput delay imposed on device-to-device traffic. If the KGR processing speed is not sufficient, an alternative approach (Fig. 5-18) might be considered. In this approach one KGRN is dedicated to header decyphering and another KGR to decyphering data packets destined for the resident LI. If additional KGR processing capability is required, KGRs can be paralleled to double the processing capability.

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*KGR is the item of COMSEC Equipment that provide encryption and decryption of data. It is more thoroughly described in Volume II

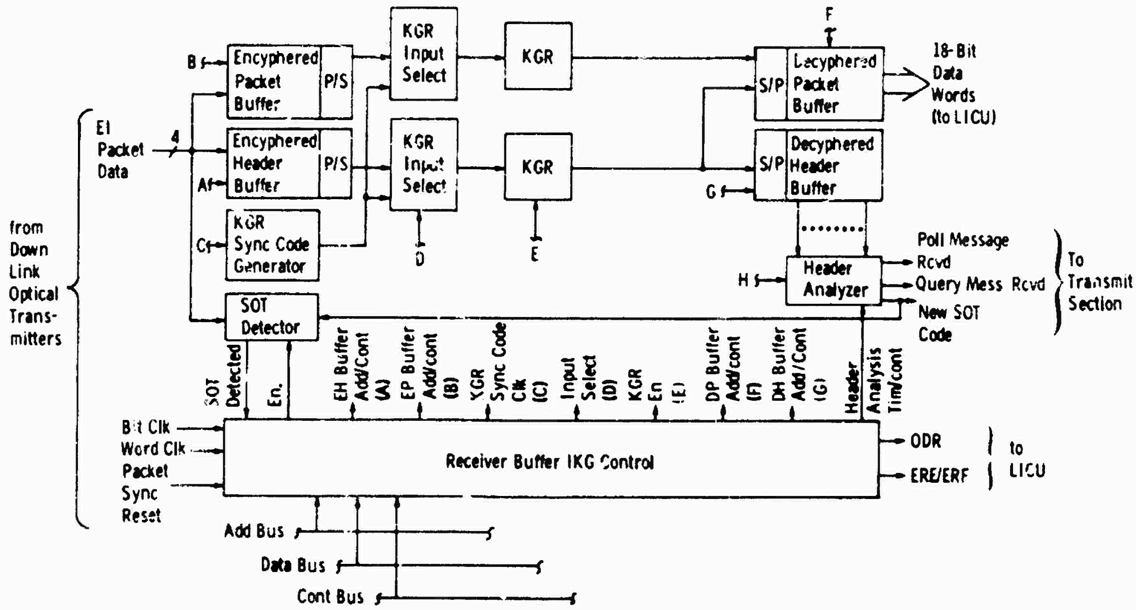


Figure 5-18. EIU receive section with two KGRs.

5.2.4 Transmission system. The EI Transmission system provides the intershelter packet transmission facility. It is comprised of the Transponder and the Optical fiber cable interconnecting each shelter with the Transponder. It is configured in a STAR Topology with a selectable number of legs (up to 64). Each leg is comprised of an uplink and downlink interfacing the transponder and shelters (Fig. 5-19). This arrangement provides for full duplex-transmission between each shelter and the transponder.

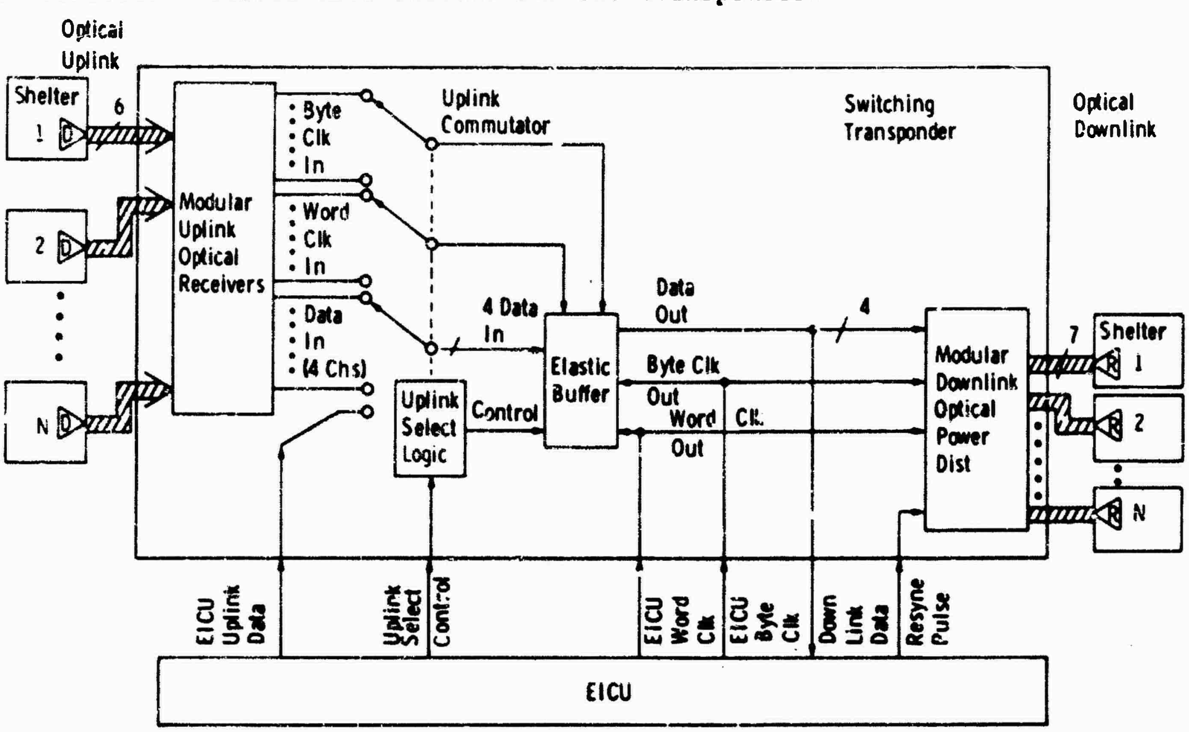


Figure 5-19. Switching transponder.

The Transponder will be housed in one of the shelters in the middle of the center, such as the Operations Central in a TACC or CRC. Futhermore, the Transponder should be collocated in the same shelter as the EICU to eliminate additional source fiber optic links between the two units for monitor and control functions. It appears that both EICU and Transponder, being single failure points of the External Intraconnect, must be redundant. The backup EICU/Transponder would be housed in another shelter, in the middle of the center, to provide a reasonable degree of survivability. Figure 5-20 illustrates the redundance scheme using optical "T" couplers connecting the up and down links of each shelter to both transponders. The "T" couplers are passive, highreliability components that will not seriously affect the availability or survivability of the FI.

The shelter/transponder links are assumed to be generally within two km of the middle of the center. However, the situation has been identified where radar and radio shelters may be as much as 8 km from the middle of the center. This, a 16 km EIU/EIU transmission path could become a reality in some FI deployments. Neither Fiber Optic nor any realizable transmission media meeting the requirements of the FI, at present, is capable of sustaining 16 km repeaterless transmission. Therefore, the transponder must act as a regenerative repeater.

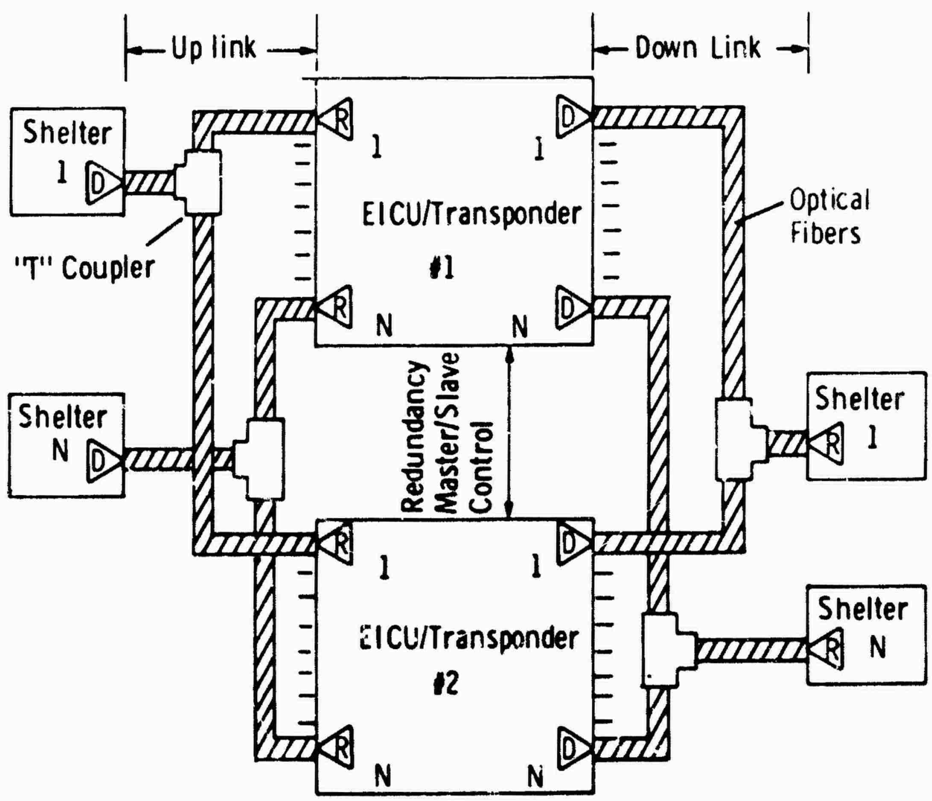


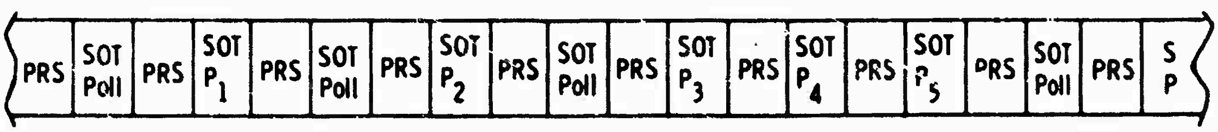
Figure 5-20. Redundant EICU/transponders.

The uplinks from each shelter contain a continuous 200 Mb/s digital transmission stream. Only one shelter or the EICU transmits a packet at one time on the uplink. All others transmit pseudo-random fill sequences on their uplinks. The transponder, under control of the EICU, switches the uplink stream of the shelter transmitting the packet into an elastic buffer for re-synchronization and regenerated baseband signal, then modulates the optical carriers on the fiber optic downlinks to each of the shelters. The transponder and fiber optic transmission media will be discussed separately.

5.2.4.1 Transponder. The transponder is a star-optical regenerative repeater which also acts as an uplink commutator and asynchronous buffer. The input to the transponder, the modular uplink optical receiver, is comprised of six optical receivers on each fiber optic uplink; four for the packet channels, one for the byte clock and one for the word clock, as discussed in Section 5.2.1. The optical receivers are discussed in Section 5.2.4.2. The optical receiver section will be modular such that each module contains a set of receivers for each uplink in the center. Using this approach, a center would use only the number of modules required to support its uplinks. Therefore, it would not be taxed with a full set of modules capable of supporting a maximum center configuration of 64 shelters. If new shelters are added to the center, then a new module would be likewise added to the transponder. The EICU is collocated in the same shelter with the transponder. Therefore, its uplink data channels are not routed through the optical receivers since fiber optic links are not required within a shelter.

The uplink data and clocks (6 lines) from the shelter, selected for downlink packet transmission by the EICU are routed through the uplink communication to the Elastric Buffer.

The commutator operates under control of the EICU. The Commutation sequence is governed by the EI polling algorithm stored in the EICU. Figure 5-21 will help illustrate the commutator function. The EICU switches the commutator to its input ports during the PRS period. The SOT code plus the poll packet are transferred into the Elastic Buffer under control of the EICU byte and word clock. The data and clocks illustrated in Figure 5-11 are typical of EICU and EIU word construction and clock relationship. The packets are strobed out of the buffer under control of the EICU byte and word clocks. When all of the poll packet words have been transferred into the buffer, the PRS, transmitted on the EICU uplink, is transferred into the buffer. The EICU will then switch the commutator to the channel that it just polled. The commutator will always be switched at the start of an EICU word.



P_n = Packet n

PRS = Pseudo Random Sequence

Poll = Polling Packets
From EICU

Figure 5-21. Typical EI selected uplink packet transmission sequence.

The PRS on the polled shelters uplink will then be transferred into the buffer until its SOT code followed by its response packet, P_1 appears on the uplink and is transferred into the buffer. After P_1 has been transferred into the buffer, the PRS on its uplink begins to be transferred into it. The output of the buffer, which is the EI downlink data stream, is constantly monitored by the EICU. When it recognizes the end of P_1, it will then switch the commutator back to the EICU input, and start transferring its own PRS back into the buffer input. At the end of the first PRS word, the EICU transfers its SOT plus the poll message to the next shelter in the polling sequence. The selected uplink packet sequence continues in essentially this same fashion of PRS-Poll-PRS-P_n-PRS-Poll. The only exception to this sequence occurs when a direct address packet is being transmitted over the EI. In this case only, a query/response routine must be exchanged between the originating and destination EIUs. This exchange is shown in Figure 5-21 by packets P3, P4 and P5. P3 is a query packet, followed by the response packet P4, followed by the data packet P5*. The EICU must analyze every packet header on the selected uplink output from the buffer to determine what switching action to take. In the query response packet exchange, it recognized that P3 was a query directed to the destination shelter and switched the commutator to the destination shelter uplink after P3 was completely recognized at the buffer output. The EICU then analyzed P4 and determined that it was an affirmative response (EIU buffer space available) and switched the commutator back to the originating shelter's uplink. It then monitored P5 to determine the end of the data packet and switched the commutator back to itself for the next poll packet.

The downlink data stream that is always clocked out of the Elastic Buffer by the EICU byte and word clocks is a continuous transmission stream (nine four-bit bytes per word). However, each shelter's uplink is asynchronous to every other shelter's uplink in the center due to two factors.

a. Transit time differential because of the difference in distances from the shelters to the transponder plus the difference in propagation delays from cable to cable. Assuming the cable propagation delay were constant at 5.1 nsec. per meter, the transmit time differential between two shelters being 8 km further from the transponder than the other, is 40.8 usec. The 50Mb/s uplink transmission rate over 40.8 usec transmit time differential produces a 226.67 word differential transit time delay** from the two shelters to the transponder.

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*This sequence assumes the destination shelter had buffer space available and responded with an affirmative response in P4. If a negative response is tranmsmited in P3, then P5 would not appear in the sequence.

**At 50Mb/s, a byte period is 20 nsec, and a word period is 180 nsec. There are 226.67 word periods in 40.8 usec.

b. Response time delays from EIU to EIU could be in he microseconds due to component and processing delays.

Only fractional word delays affect the uplink/downlink phasing, since only word alignment is required in the transponder. The EICU controlling the commutator switching guarantees proper alignment of packets and PRS words. The differential in word arrival times between the various shelters in the center is absorbed by the Elastic Buffer.

The Elastic Buffer is a byte-oriented asynchronous buffer in which data bytes are written into it under control of the selected uplink byte clock and read out under control of another indepeadent byte clock from the EICU. The relative phasing of the write in/read out clocks can vary within the confines of the buffer size such that the buffer never overflows or depletes. A buffer sizing of ± one word (± 9 bytes) would guarantee no loss of data when switching from one uplink to another. When the commutator switches from one uplink to another, during the PRS periods on each uplink, bytes are dropped from the newly selected uplink PRS in the Elastic buffer to align it with the EICU word and byte clocks.

The four channels of the selected uplink are transferred out of the Elastic Buffer by the EICU byte and word clocks into the Modular Downlink Optical Power Distributor. The byte and word clocks are also routed into the distributor along with a SOT resync pulse. The resync pulse stream is discussed in Volume II. The function of the optical power distributor is to convert the selected uplink data channels plus the ECIU clocks and resync pulse stream from the electrical domain to the optical domain and drive each of the seven fiber downlinks to each of the shelters in the center.

There are two approaches to the optical power distribution function. First is the unsophisticated brute force approach of buffering the electrical data and clock signals and then driving the seven fibers of each downlink individually. This approach requires seven line drivers for each downlink driver module. Seven injection lasers and drivers are required in this approach. The power distributor must also be modularized such that a center needs only the number of line driver modules required to drive its downlinks. The line drivers are discussed in Section 5.2.4.2.

An alternate approach that could prove a considerable cost saving and should be considered in the hardware design phase, is the use of a single fiber-optical star coupler. The star coupler is driven by a single injection laser and the power then divided evenly to each of the output parts. The analysis in Section 5.2.4.2 will show that an n/port star coupler could be used in a 2 km distribution system, but the loss is too great for 8 km distribution. If the star coupler proves reliable for a 2 km center, any links greater than 2 km up to 8 km could be driven by individual drivers. The implementation of the optical power distributor is a hardware implementation problem and can be addressed in the future, and in no way affects the feasibility or realizablity of the FI.

A non-switching transponder (Fig. 5-22), was considered, but discarded as a general solution to the EI optical distribution problem. The difference in this approach from the switching transponder is in the uplink receiver and selection (commutator) functions. All fibers from each uplink channel are collected together in a bundle connector and coupled to a large area photo detector. Thus, all data channel number 1s from each shelter are coupled together in one connector, data channel number 2s in another connector, and so forth. Large area detectors (65 mill diameter surface) are avalable accept a single fiber from all 64 shelters, the maximum center configuration.

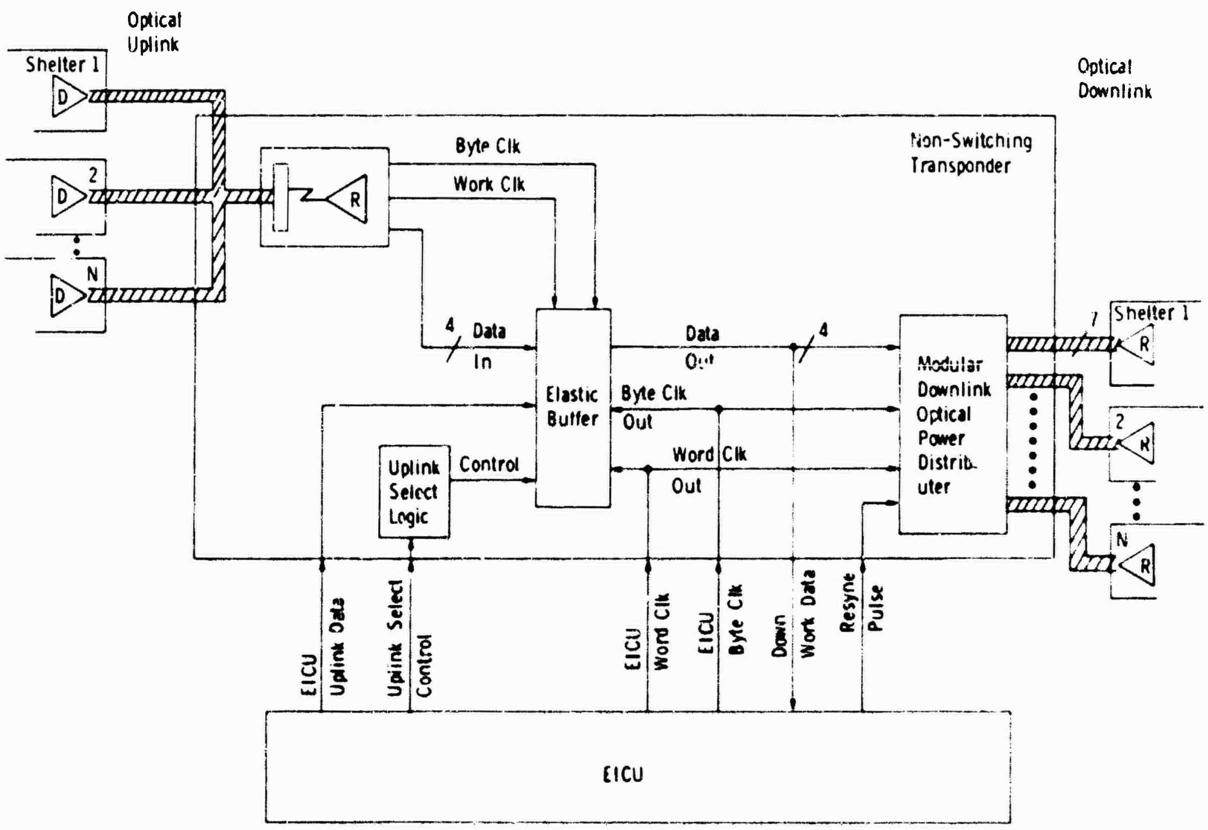


Figure 5-22. Non-switching transponder.

Since the uplink fibers of a channel from each shelter are all incident on the same detector, only one shelter optical tramsitter may be enabled at a time. This requires the uplink transmission from the shelters be of a burst nature rather than a continuous stream of a PRS interspersed with packet transmissions. An example of packet only transmission is illustrated in Figure 5-23. The packet sequencing of the selected uplink stream in this approach is implemented by the polling function alone, and no commutator is required. The output from the six optical receivers are routed to the elastic buffer from which point the rest of the transponder operation is the same as the switched transponder. The downlink data stream is the same for the non switched as for the switched transponder.

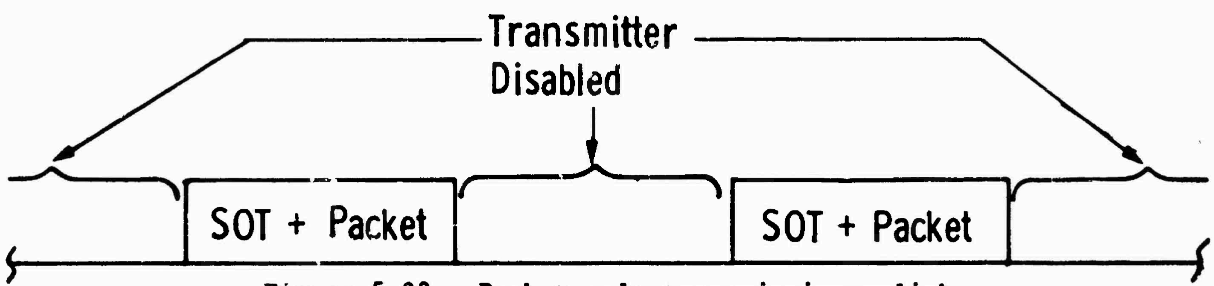


Figure 5-23. Packet only transmission uplink.

This approach requires only six optical receivers in the transponder for the entire center, thus eliminating the need for six optical receivers for each shelter uplink in the center. The potential cost savings in this approach is quite substantial due to the high cost of the optical receivers. The simplification of the transponder and the cost savings, however, are offset by three major operational disadvantages which lead to the elimination of non-switched transponder as a viable candidate.

a. Reduction in traffic flow security. By monitoring the uplinks for activity only, the frequency of information transmission and the length of the transmission can be determined. Some masking of the transmission can be accomplished, but the inherent compromise of traffic flow security cannot be eliminated.
b. Jamming susceptability. If any fiber cable can be accessed, continuous light energy could be injected into the uplink fibers, thereby incapacitating the entire EI transmission system.
c. EI transmission system reliability. A failure in the tramsit section of any EIU such that its optical transmitters are continuously on would render the entire EI transmission inoperable. Protection could be built into the EIU to disable the optical transmitters after a fixed transmission time which could increase the EI transmission system availablility.

Only if a situation occurs where these three factors are not significant, could the non-switching transponder possibly be advantageously used.

5.2.4.2 Fiber optic transmission system (Digital Signals). The fiber optic transmission system provides the up and downlink interconnection between the transponder and the EIU. Fiber optic transmission was chosen over other candidate transmission technologies because the advantages peculiar to fiber optics more closely match the EI transmission requirements than other candidate techniques. Some of the advantages of fiber optic communications are:

a. Complete electrical isolation between transmitter and receiver (no lightning hazard or ground current problems);
b. Immunity from external EMI/RFI and EMP (no electromagnetic fields in dielectric);

c. Inherently wide signal bandwidths;
d. No conducted or radiated emissions;
e. Crosstalk between adjacent fibers within a multifiber cable is very small (80 to 100 dB down; photon energy not totally reflected back into core of fiber is almost totally absorbed in cladding material);
f. Inherent transmission security (tapping of a fiber involves signal splitting which leads itself to transfer detection as a reduction in received signal energy);
g. Digital or analog modulation capability;
h. Assembled fiber cable physically small and lightweight;
i. Components stable over a wide operating temperature range;
j. No spark or fire hazard; and
k. Fiber attentuation is independent of temperature variations.

One illustration of the advantages that fiber optic implementation of the EI offers is its comparison with the present multiwire cable shelter when separations of 0.5 km (1500 ft.) are considered; the same techniques can be applied at much greater separations. The light weight of the fiber cable means increased length per reel with no increase in total reel weight, whereas it takes six reels of CS-4566 cable at 75 lb per reel to cover 1500 ft. One reel of fiber cable weighing less than 35 lb can do the same job for a weight saving of over 92 percent.

Multi-fiber cables can be used to increase the total throughput without appreciable increase in cable size. Fiber optics cable has both size and bandwidth advantages over coaxial cable, e.g., RG-63/U low-capacitance cable is nominally 0.405 inch in diameter while PVC jacketed multifiber cable is typically 0.25 inch in diameter. As such, fiber cables can easily be stored and transported. Additionally, fiber cable can easily be drawn (with a low degree of concern for fiber breakage) through both horizontal and vertical cable shelter ducting. Noninformation-bearing strengthened-cable members either metallic or nonmetallic, can also be used if necessary, for installing long-haul communication links in strategic and tactical environments. The inherent wide-bandwidth characteristics of a fiber optics link result in advantages not readily obtained with wire systems.

First, the attentualtion characteristics of currently available low-loss fiber are, unlike coaxial cable, independent of baseband frequency. Low-loss, high-silica fibers can be purchased today with attenuation that approaches the Rayleigh scattering limit, i.e., 2 to 5 dB/km, at the transmission wavelength of interest; at least an order of magnitude less than good quality coaxial transmitting at the same baseband frequency. One net advantage is that long, unrepeatered data links (8 to 10 km) are possible with fiber optics communication systems. Corresponding long-wire links generally require powered repeaters at intervals less than 1 km.

Second, a wide-bandwidth fiber link easily accommodates an increased data rate through multiplexing techniques by modification of the electro-optical transmitter and detector circuits-provided a wideband fiber is

initially selected. Future data-rate requirements need not require the replacement of cables to achieve better transmission performance. There is a disadvantage, however, in that logistics and parts qualification factors must be considered for reliable operation, installation, and maintenance. Operating and maintenance personnel must gain experience with optical parameter measurements, e.g., low-power levels, and fiber interconnections.

The EI transmission requirements identify the design parameters imposed on the fiber optic transmission system. Since the high-speed digital and analog transmission requirements and design differ significantly, they will be discussed separately below.

a. High-Speed Digital Data Links: The design parameters imposed on these links are:

1. Transmission distance up to 8 km;
2. Digital data rate of 200 Mb/s (4 SDM channels @ 50 Mb/s each); and
3. BER: 1×10^{-8}.

5.2.4.2.1 Fiber optic transmission system components. Component types evaluated in this preliminary investigation of the fiber optic transmission medium include optical transmitters, single-fiber and multi-fiber cables, and optical receivers. Currently, LEDs and solid-state injection lasers (ILs) are the only elements under consideration in the optical transmitter electronics. Correspondingly, two types of photodiodes are of prime interest for operation within the optical receiver. The two solid-state photodiode detectors most suited for medium to high bandwidth/long-haul communications for optical fiber applications are the PIN diode (containing positive (P), intrinsic (I), negative (N) layers) and the APD (avalanche photodiode). Optical receivers for this application would use one of these photodiode detector types since both exhibit high quantum efficiency, speed, and general availability. The APD is generally more costly and uses a high-voltage power supply (250V at 10 nA). However, the APD with internal avalanche gain provides greater receiver sensitivity than the PIN receiver. The power budget analysis discussed later in this section will show that only the APD, with its greater sensitivity, is capable of providing the 10^{-8} BER for 50 Mb/s transmission over 8 km of low-loss fiber.

The solid-state LEDs and laser diodes used within the optical transmitter are conveniently modulated by varying their bias current. Most of these devices emit peak light power at approximately 840 nm in the near-infrared portion of the spectrum. This peak output power region matches the low attenuation region of optical fibers to maximize transmission efficiency. An additional positive attraction of the fiber optics system is that the light-emitting surface area of both the LED and IL are dimensionally compatable with the light-acceptance angle of many fibers and fiber bundles.

This dimensional compatability is essential in minimizing source-to-fiber coupling losses. The LED voltage-current transfer characteristic is generally more linear than the IL transfer characteristic and, for this reason, its use is more readily adaptable for both digital and analog (radar video) modulation techniques. On the other hand, ILs have a greater power output, lower spectral spread, and narrower emission angle than an LED, which can, in turn, be translated into longer transmission paths such as the 8 km required in the EI. When used in a digital data path, the IL is intensity-modulated from fully off to fully on, and an NRZ data format can be used. Commonly used data formats also include a return-to-zero (RZ) and unipolar Manchester coding, which impact directly the average link power calculations and complexity of digital receivers.

The graded-index multimode fiber was chosen as the transmission medium of the EI because its low modal dispersion characteristics in conjunction with low attenuation characteristics allow for repeaterless transmission of 50 Mb/s digital data over a distance of 8 km with less than 1×10^{-8} BER. One candidate optical fiber being considered, and one which meets the attenuation and model dispersion criteria for EI transmission is the graded-index multimode optical fiber manufactured by ITT (Type T-221). The fiber consists of a silica core, doped to produce a graded-refractive index profile, and a borosilicate cladding. It has 5 db/km attenuation at a wavelength of 850 nm and a -3 dB intermodal dispersion of 1 nsec/km. The numerical aperture is 0.25, which corresponds to an acceptance core half-angle of about 14.5 degrees. Another candidate is Calwing's Coreguide 2041 (recently introduced) which is a gladed-index fiber with approximately 0.8 nsec/km intermodal dispersion and an attenuation of less than 2 dB/km at 900 nonometers wavelength.

Step Index fibers, even though they exhibit low attenuation characteristics, were discarded for EI transmission because their relatively high intermodal dispersion (on the order of 15 nsec/km) renders them incapable of supporting 50 Mb/s tramnsmission over several hundred feet. A fiber cable assembly of thirteen T-221 or Coreguide 2041 fibers will be required to meet the requirements of six uplink channels and seven downlink channels of the digital tramsmission system.

Fiber bundles (wherein the multiple fibers carry the same information) are bulky, not usually strengthened, and generally marked by higher spectral attentuation and modal dispersion, and for these reasons were not considered viable for EI transmission.

5.2.4.2.2 Power budget analysis. The power budget was first determined by assuming an Injection Laser (IL) source, driving four two-Km sections of cable in series between two shelters, as illustrated in Figure 5-24. The up and downlinks are transmitted continuously on separate cables providing full-duplex communication between the shelters. Table 5-1 and 5-2 illustrate the power budget. The IL source output power is assumed to be 10 dBm which is typical of high power ILs. The cable can be purchased in 2 km lengths which require seven connectors as shown in the figure. Good optical connectors exhibit less than 1 dB loss, for a total connector loss of 7 dB. The resulting

receiver input power is -42 dBm for the T-221 cable and -18dBm for the Coreguide 2041. The digital receiver performance curves (Fig. 5-25) for a BER of 1x10-8 indicate that a 50 Mb/s data rate the minimum receiver power input for a PIN detector is -54 dBm. Thus, only an APD receiver will meet the EI transmission requirements with a power margin of 12 dBm when using the T-221 cable. A PIN detector could be used with the Coreguide 2041 with an 18 dBm margin.

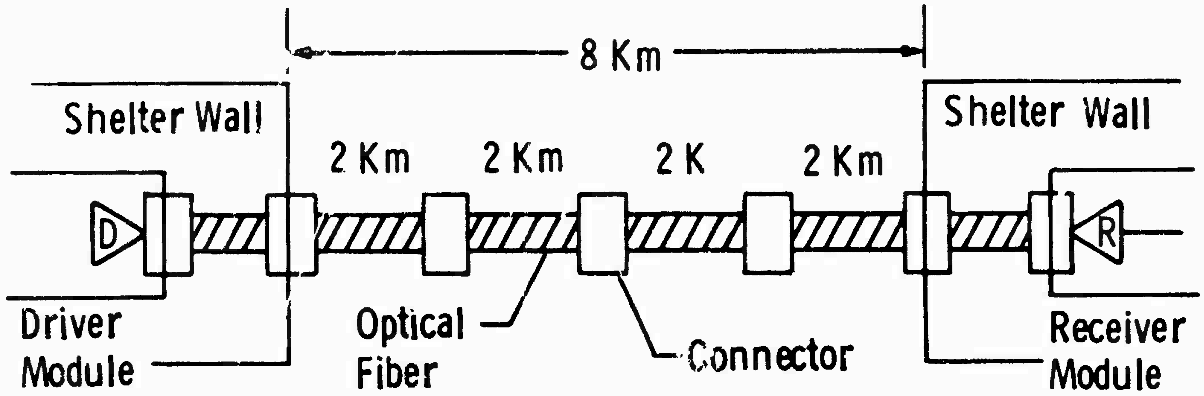


Figure 5-24. 8 km intershelter fiber optic link.

TABLE 5-1. POWER BUDGET T-221 FIBER

	Power Level (dBm)	Power Loss (dB)
Source Output Power (IL)	10	
Coupling Loss (Source/Fiber)		-4
Fiber Attenuation (8Km) at 5 dB/Km		-40
Seven Series Connectors at 1 dB/conn		-7
Coupling Loss (Fiber/Detector)		-1
Receiver Input Power	-42	-52

TABLE 5-2 POWER BUDGET (COREGUIDE 2041)

	Power Level (dBm)	Power Loss (dB)
Source Output Power (IL)	10	
Coupling Loss (Source/Fiber)		-4
Fiber Attenuation (8 km) @ 2 dB/km		-16
7 Series Connectors @ 1 dB/Conn		-7
Coupling Loss (Fiber/Detector)		-1
Receiver Input Power	-18	-28

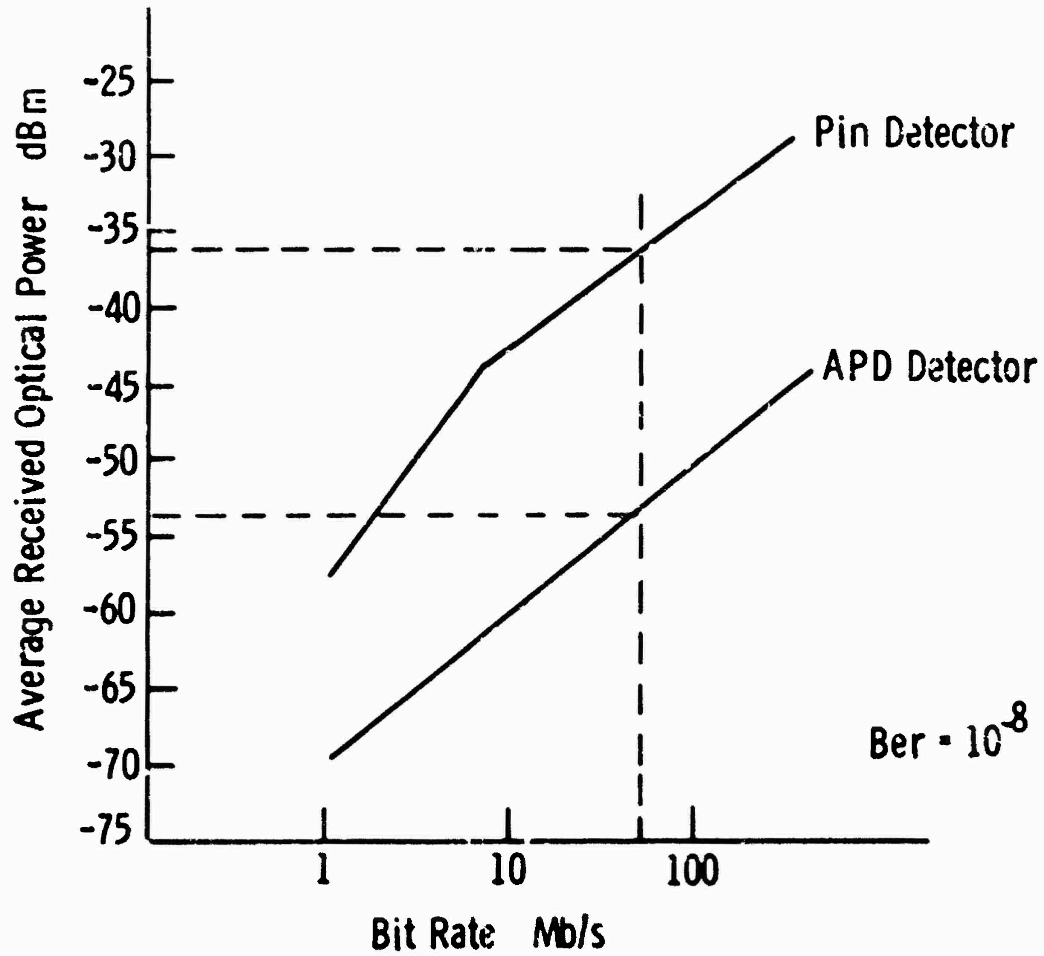


Figure 5-25. Digital receiver performance.

error performance is actually much better than 10^{-8} in either case because the BER decreases dramatically with small increases in optical power as the receiver SNR passes through the neighborhood of 20 dB.

An LED will not provide the required 10^{-8} BER performance when coupled to the T-221 cable, due to its lower output power (+3 dBm) and the high-source-to fiber coupling loss of approximatley 20 dB. The resulting receiver input power is 23 dB lower than that of the IL of -65 dBm. In this region a 1 dB increase in optical power results in a reduction of the BER to 10^{-10}. On shorter links, up to 6 km where the loss is 11 dB lower (10 dB for 2 km plus 1 dB for one less connector) the receiver input power with the T-221 cable is -31 dBm which according to Figure 5-25 indicates a PIN detector is sufficient with 5 dBm margin. An LED could provide the required Power level to insure a 10^{-8} BER, when coupled to the Coreguide 2041 cable and an APD detector, with a 14 dBm margin.

A more efficient approach to transmission of the digital EI channels, in which considerable fiber optic cable savings can be realized, is the implementation of full-duplex transmission of the up and downlinks over the same fibers. Figure 5-26 shows this operation, which is based on bidirectional, wavelength multiplexed transmission over a single fiber. The approach requires a bidirectional "T" coupler on each fiber at each end of the cable, i.e., at the shelter and at the transponder. Different wavelength ILs are required for the up and downlinks. The figure shows the driver at the shelter using a source of wavelength, λ_1, and the transponder optical source emitting power at wavelength, λ_2. The two source types could operate at two standard fiber optic component wavelengths, 850 nm and 900 nm, which provide sufficient separation for the system. Optical filters are also required in front of the receivers at both ends of the cable. The filters pass the optical signal power from the driver at the opposite shelter into the optical receivers, and attenuate the signal from the driver in the same shelter. For example, the optical filter ($\lambda 2$) in the transponder passes te uplink signal ($\lambda 2$) from the shelter and attenuates all other wavelengths, including $\lambda 1$ from the downlink drivers in the transponder. The filters prevent the downlink signals from feeding back into the uplink receivers and swamping the uplink data. The same is true for the $\lambda 1$ filters on the shelter downlinks.

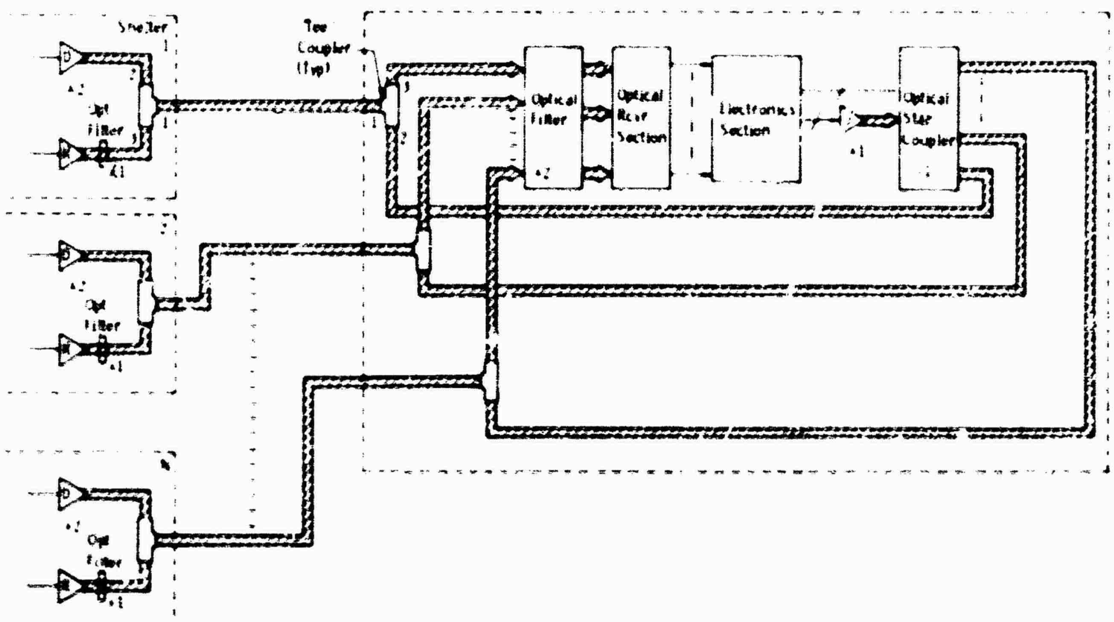
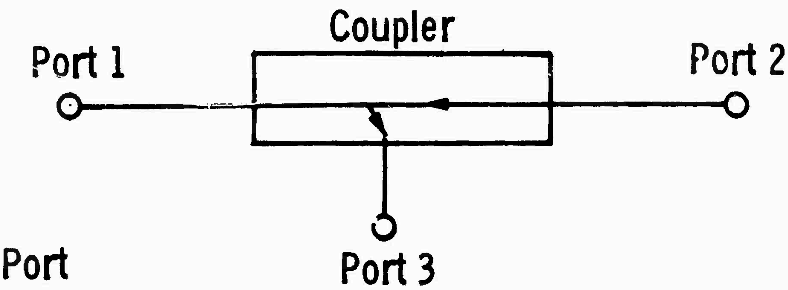


Figure 5-26. Bidirectional up-downlink transmission over single fiber.

Glass-on-glass fiber-compatible couplers compatible with either stepor graded-index fiber are available which include directional wavelength-duplexing couplers allowing bidirectional, wavelength-multiplexed transmission over a single optical fiber. One coupler indicative of the candidates to be considered is the Three-Port Wavelength Duplex Directional Coupler manufactured by ITT (T-778). The port-to-port directional transmission and insertion loss of the coupler is shown in Figure 5-27. The coupler loss from Port 2 to Port 1, which is the driver to intershelter fiber path, is 1.5 dB. The coupler loss from port 1 to port 3, which is the intershelter fiber to receiver path, is 10 dB. The additional transponder/shelter path loss due to the two bidirectional couplers is 11.5 dB. An additional 2 dB loss will be realized in the optical filter that, combined with the coupoles losses, adds a 13.5 dB loss to the optical transmission path.



Port-to-Port Insertion Loss

Port/ Port	Loss* (dB)
2 to 1	1.5
1 to 3	10.

*at 850 nanometers

Figure 2-27. ITT three-port directional coupler.

The resulting receiver optical input power is reduced to -55.5 dBm, which is -1.5 dBm below the required input power to provide a BER of 1x10-8 at 50 Mb/s (see Fig. 5-25). A higher outut power IL (14 to 15 mu) in the driver lower loss connectors (-0.5 dB/connector) would increase the input power sufficiently to reach the required -54 dBm. Both higher power ILs and lower-loss connectors are claimed by manufacturers and should be standard specifications within the next two years. Using Coreguide 2041 cable, wavelength multiplexing results in receiver input power of -31.5 dBm. Thus a PIN detester could be used to provide a 4.5 dBm margin, or an APD detector with a 22.5 dBm margin.

5.2.4.2.3 Optical modulation techniques. For optimum performance (maximum SNR), the receiver front-end noise must be minimized. Since the total noise increases with receiver bandwidth, the optimum receiver design should have a narrow band front end at the fundamental frequency of the digital data signal. The wideband nature of NRZ modulated 50 Mb/s data is not amenable to

narrow-band processing. Another problem with NRZ modulation is that long strings of ones or zeroes can occur in random data. This can cause problems in high-speed fiber optic links, since all light pulses are unipolar, and can cause dc drift errors in the receiver. The ac coupling in the receiver (used to eliminate the drift), cannot be used in NRZ receivers because the power spectral density is non zero as the baseband signal approaches dc, due to long strings of ones and zeroes.

Forms of RZ modulation such a Biphase (Manchester coding) were also considered, but these modulation techniques are not optimum either since they are also wideband and have a fundamental twice that of NRZ. The spectrun of the fundamental of an NRZ modulated baseband signal lies between zero for a long string of ones and zeroes and one-half the information rate for an alternating one/zero pattern. An RZ modulated baseband signal's frequency spectrum lies between one-half the information rate for an alternating one/zero pattern and the information rate for a long string of ones or zeroes. RZ modulation allows ac coupling in receiver and makes it more attractive than ARz, but requires a wideband receiver front end of 25 MHz, which makes it unattractive. Both phase and frequency shift keying techniques might offer improved receiver performance and should be considered in the EI transmission design in Phase II.

5.2.4.2.4 Intermodal dispersion analysis. To avoid data-bit sampling errors due to intersymbol interference caused by pulse jitter, the overall system rise time must be kept to within approximatley 70 percent of the pulse width for NRZ-type data formats or 35 percent for RZ formats. Since some kind of RZ modulation is required on the four 50 Mb/s EI data channels, the system rise time of the fiber optic transmission system must be less than 7 nanoseconds. The individual rise times of the IL source, fiber (due to intermodal and material dispersion) and receiver rise times can be combined in a root-sum-of-the-squares (RSS) fashion to determine the system rise time.

A 1.5 nonosecond rise time in the IL, 2 nanosecond rise time in detector and a 1 nsec/km cable yields a system rise time of approximately 8.4 nanoseconds, which is 42 percent of the data period. This leaves only 1.6 nanosecond margin, which is unacceptable for low-error data detection. An 0.8 nsec/km fiber with the same IL and detector yields a 6.87 nanosecond system rise time which is acceptable for low-error data detection.

5.2.4.2.5 Conclusions. The EI digital transmission requirements for a channel data rate of 50 Mb/s over 8km while providing a BER of better than 1×10^{-8} can be met with a fiber optic transmission system implemented with components presently available. The components required to implement the system represent the present state-of-the-art. The significant component specifications are listed below:

a. Injection Laser - 10 mw peak cw output power, 1.5 nanosecond maximum rise time.
b. Optical Fiber - $\leq$ 4 dB/km, $\leq$ 0.8 nsec/km graded index fiber.
c. Detector - ADP, high responsivity and quantum, efficiency, 2 nanosecond rise time.
d. Optical Connectors - $<$ 1 dB per connection.
e. Optical Couplers (if wave length multiplexing is used) - three port wavelength duplexing directional coupler, 2 coupler I/O insertion loss $\leq$ 14 db.

Even though these components represent the state-of-the-art today, they are expected to be standard off-the-shelf components in two to three years in the future. The use of components with less stringent specifications is recommended when the shelter/transponder cable distance is less than 8km.

5.2.4.3 Fiber Optic Transmission System (Analog Signals). Extra fibers will be supplied in the EI multifiber cable for transmission of special signals such as the radar video and digital information from the AN/TPS-43 radar to the AN/TSQ-91 CRC operations central. This portion of the EI transmission system would transmit the radar video and digital signals from the radar to the OPS in a simplex dedicated manner. A single fiber could be used for the four 6 MHz video outputs and the corresponding 6 MHz video trigger along with the height and azimuth information. FDM multiplexing, either electronically with the subsequent driving of the optical fiber source, or by directly modulating the light energy using an electro-optical or acoustic-optical modular can be used to implement these functions this design decision will be made in Phase II.

To illustrate the level of performance that can be expected by transmitting the radar video signals through a good-quality fiber optics waveguide, a representative link is assumed. An injection laser (IL) source can be intensity-modulated about a quiescent output midpoint to allow transmission of both positive and negative signals. The IL driver would be designed to act as a pure current source under control of the input voltage signals, which tends to compensate for nonlinearities of the IL voltage-current characteristic. Both an APD receiver and a PIN receiver were evaluated in the analysis of the link margin. Typically, the sensitivity of the APD receiver with a 40 db SNR and a 6 MHz bandwidth is -40 dBm. Under the same conditions, the average power required for a PIN detector is approximately -35 dBm (Figures 5-28 and 5-29). The IL-to-fiber coupling losses in conjunction with the degradation effects of time and temperature on the intensity-modulated IL would result in an optical output power level of -6 dBm coupled into a 0.25 NA single fiber. The same power budget described in Section 5.2.4.2.2 was used in this analysis.

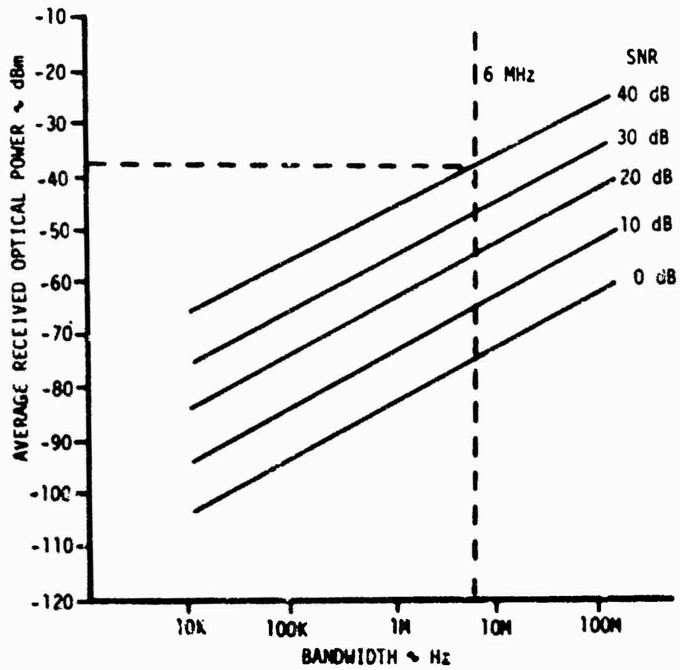


Figure 5-28. Analog receiver, ADP detector performance.

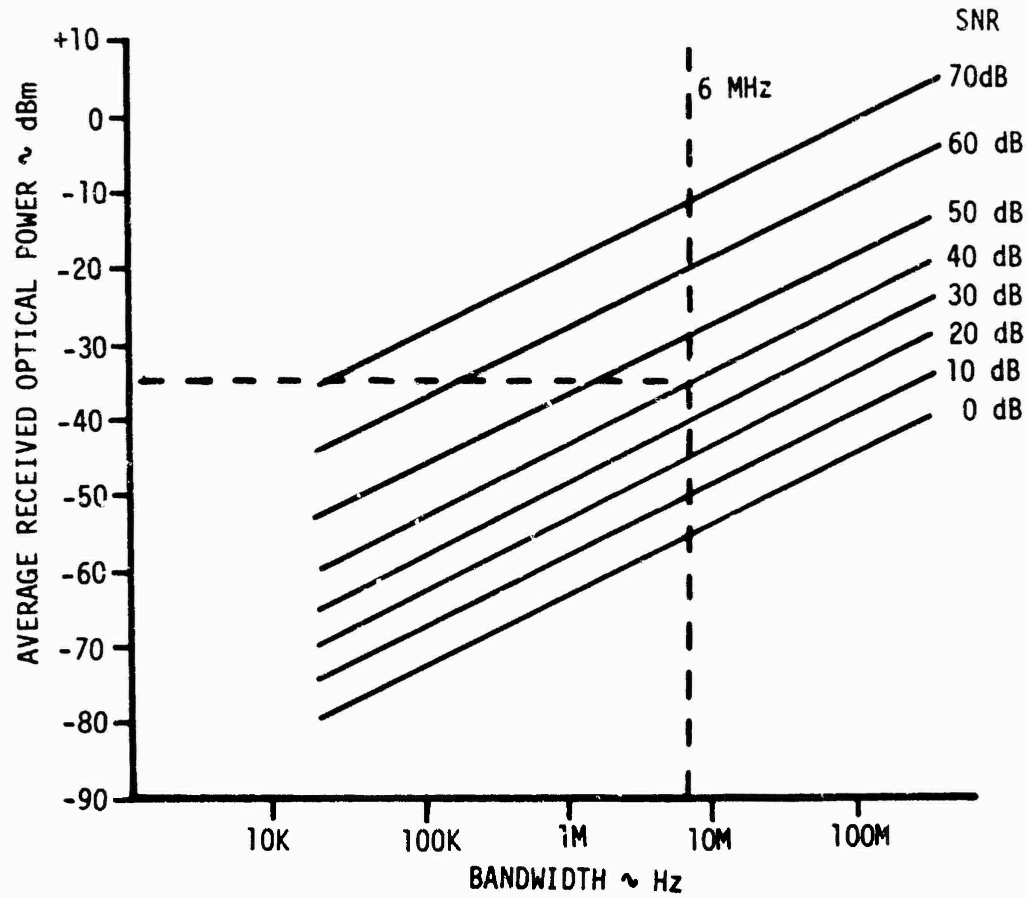


Figure 29. Analog receiver, PIN detector performance.

The analog receiver input power for a transmission system using the T-221 fiber cable is -42 dBm. Thus, an 8 km link of T-221 fiber does not meet the 40 dB SRN for 6 MHz analog signals with either an APD or PIN detector. The receiver input power of a system using Corgiude 2041 is about -18 dBm, which provides large enough receiver power with either an APD or PIN detector to guarantee the 40 dB SNR. The receiver input power margins are 22 dB for an APD detector and approximately 17 dB for an PIN detector.

Unlike the 50 Mb/s up and down link channels, the transmission of video and related digitized radar data, i.e., azimuth and height information is unidirectional. As such, wavelength multiplexing for bidirectional transmission on a single fiber is not a consideration here.

The 1 nanosecond/km intermodal and material dispersion of the T-221 fiber coupled with a 1.5 nanosecond rise time in the IL, and a 2.0 nanosecond rise time in the analog receiver yields a system rise time of approximately 8.4 nanoseconds. This compares quite favorable with the maximum allowable dispersion of 58 nanoseconds, which for intensity-modulated analog signals, is estimated to be approximately 35 percent of the fundamental period of the 6 MHz video signals. Therefore, the use of either T-221 or Corguide 20-41 fibers will meet the radar transmission requirements in the TAF center.

5.3 FI system control. The FI's capacity to meet the data transmission requirements of the ADP and communication terminal equipments, comprising a variety of data rates and structures, requires flexible system controls be incorporated into the FI Design. FI system controls function is a hybrid of both centralized and distributed control, i.e., some control such as device network configuration control is centralized, while others, such a LI data transmission control is distributed. The system control functions were defined in the study as either human or automatic equipment controls. The aspects of FI system control which were addressed in Task III of this study are discussed in he following sections. The control functions are categorized under the three operational modes: Deployment, System Initialization and Data Transmission for convenience of the discussion.

5.3.1 Deployment mode. The Deployment Mode consists predominantly of human control. Duirng this mode, both the LI and the EI must be fully defined according to the TAF center configuration, and its subsystems must also be physically programmed and interconnected by the LI and EI transmission media. The deployment functions are listed below for both the EI and the LI.

LI deployment.

a. LIU address programming - Each LIU must have its address stored in non-volitile memory such that it will be preserved in the situations of transients, power loss, or LIU failure. The memory media will most likely be PROM or by a bank of miniature switches not easily accessable from the exterior.
b. LIU cabling - The LIUs location on the LI cable must be defined (n feet from the LICU, between LIUs x and y, etc.). The LIUs and the LICU must also be cabled up, probably using flat ribbon cable and a type of insulation displacement connectors as described in Appendix 11.3 for ease of addition of deletion of LIUs from the LI cable.
c. SAU programming - The SAUs must also be programmed for their particular functions of format and electrical signal transformation, and data transfer protocol routines to provide compatability with the FI interface standard, for devices which do not inherently meet it.
d. Device (SAU) cabling - The devices (SAUs) must be cabled to the LIU.

EI deployment.

a. EIU address programming - Each EIU must have its address stored in nonvolatile memory, the same as the LIU.
b. EIU configuration programming - The EIUs configuration data (number of EI channels, number of KGs, etc.) must also be stored in non-volatile memory.
c. EI physical layout definition - The data defining the physical layout of the FI as listed below, must be generated:

    1. Number of shelters on EI;
    2. Location of EIU (by address) on the transponder (port number);
    3. Transmission system (for each shelter).

a) Transponder interface media (fiber optic),
b) No. of up/downlink digital channels (no. of fibers for digital transmission,
c) No. of analog channels (no of fibers for analog transmission),
d) Transmission rates (digital and analog),
e) Cable length.

4. Number of KGs in the EICU.

d. EIU cabling - The fiber optic cables connecting each shelter to the transponder must be installed along with the EIU/LICU (FI standard interface) cabling.

When the system deployment is completed, the System Initialization Mode can begin.

5.3.2 System initialization mode. After the system has been deployed, and as each subsystem is powered up, it initializes itself in a general start-up mode. The subsystems must then be initialized to the particular configuration of the TAF center. The initialization of the system is under the control of the communications officer and FI Manager subsystem. The System control block diagram is illustrated in Figure 5-30.

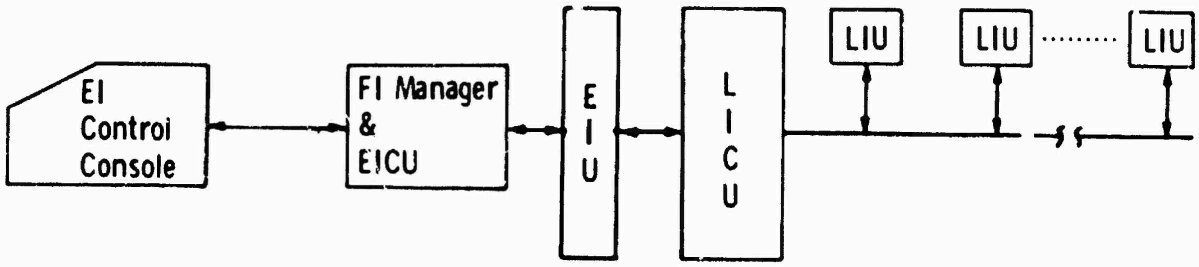


Figure 5-30. System control block diagram.

The first step of the initialization process occurs by the communications officer testing the FI Manager with an initialization test routine and then loading the FI database into its nonvolatile memory. The FI Manager must store the database for each subsystem in the FI such that it can reinitialize the subsystem after a failure has caused the loss of part of all of its operating database. The data transmission function, as well as the diagnostic and error control functions in the FI, are under distributed control, and, therefore, the database must also be distributed. A preliminary definition of the system control area of the FI database is discussed below. The tables and listings described below are intended to illustrate the type of data, required for system control, that will be required in the FI database. The data contained in, and format of the listings should in no way be construed to be the results of an extensive database design effort. The data resulted from the listings of information required at the various points in the FI system during the system control study during Task III. The database is listed under each subsystem and component where it is used.

FI Manager. The part of the system control database which is stored in the FI Manager is listed in Table 5-3.

TABLE 5-3. FI MANAGER DATABASE (SYSTEM CONTROL)

Device Identification Table
Device Opetation Table
LIU State Table
Device Status Table
Network Table
EI Address Table
Error Reporting
EI Address Table
Error Reporting
EI Database
LI Database

a. Device identification table: This table contains all the identification and classification information required to perform the communications function of every device serviced by the FI. The contents of the table are discussed below. They are also listed in Table 5-4 for convenient access.

TABLE 5-4. DEVICE IDENTIFICATION TABLE

V.A. No: n
Real Address (LIU)
Device Type
Sync/Async
Rate
Active/Passive
Adaptor Type

1. Virtual Address (VA)/Real Address (RA) - A virtual address is a convenient unique number assigned to each device serviced by the FI to identify it separately from any other device in the FI. A real address is a unique number assigned to each LIU in the FI to identify its real location on an LI used for routing data within the FI. This entry correlates the devices VA to a specific RA (LIU) on the FI.
2. Device type - Identifies the type of equipment the device is, such as processor, disk controller, TTY, Telephone, etc. This information may be helpful to the FI Manager in determining whether two devices should be allowed to intercommunicate over the FI. It may also be useful as a diagnostic tool.
3. Sync/Asnch - Identifies the device as either a synchronous or asynchronous data transfer machine. The FI must appear as a circuit switch to synchronous devices such that bit count integrity (BCI) is preserved in their data streams. The degree of non-homogeniaty in the polling of these devices LIUs is dependent on the amount of elastic buffering is provided in their SAU's.
4. Rate - Defines the devices data transfer rate and if it is constant or not.
5. Active/Passive - Identifies the device as being only a data source, only a data receiver, or both.
6. Adapter type - If the device requires an SAU, the information may be needed by the FI Manager to determine if the SAU type matches the device type for either allowing the device to be added to a network or for diagnostics purposes.

The Device Identification Table will probably be listed according to virtual address, either by numerical sequence or selective grouping.

b. Device option table: This table contains the priority classmarks for each device on the FI, defining the services granted to it by the FI. The contents of the table are discussed below, and listed in Table 5-5.

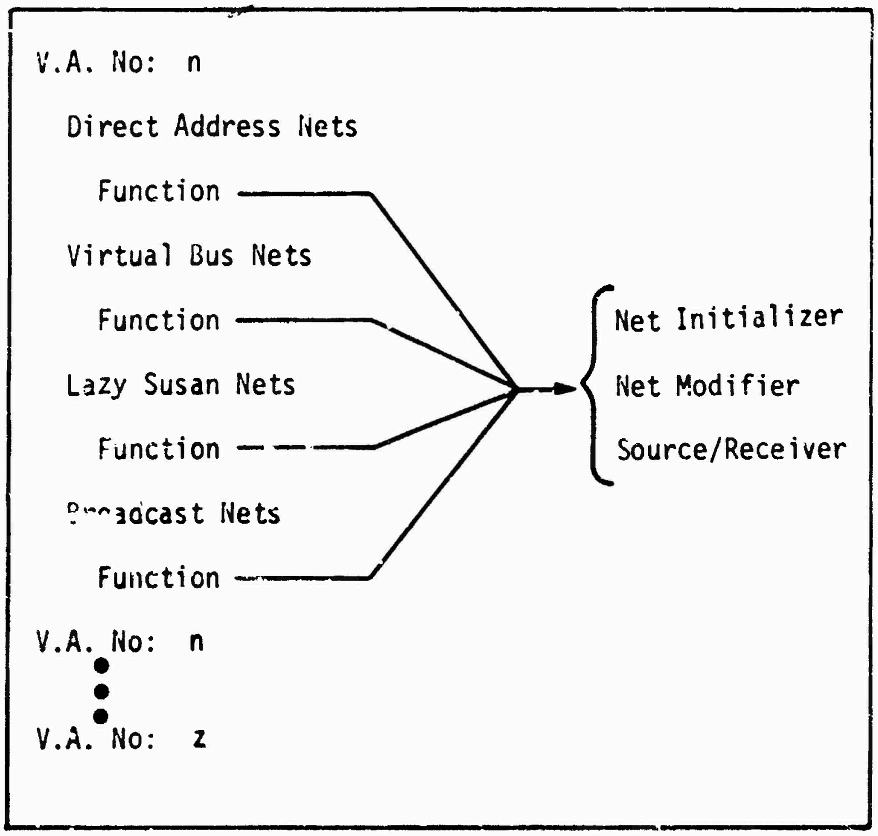
   1. Net type - Identifies which type of device networks the device is allowed to participate in.
   2. Net function - Identifies which functions the device may perform on each network type.

      a) Net initializer - A device may be allowed to request a new net of a particular type be established, while it may not be allowed to request the establishment of another type of device net. For example, a device may be able to establish a direct address net, but not allowed to establish a Lazy-Susan Net.
      b) Net modifier - A device may be allowed to modify certain device nets it is participating on, even though it may not have established the nets. Also, it may not be allowed to modify other types of device nets it is participating on. For example, a device may be on a net that it did not establish, but is allowed to modify the net, maybe by adding more devices on the net.

c) Source/Receiver - Identifies, for each device net it is allowed to participate on, whether it may act as a source only, receiver only, or both. A device may act as both source and receiver on virtual buses, but be only a receiver on the EI broadcast net.

4) Priorities - Identifies the levels of priority the device may invoke or the levels of priority the device may place on certain nets it is participating in.

TABLE 5-5. DEVICE OPTION TABLE



The Device Option Table might be listed according to Virtual address. Under each virtual address the listing would most probably be according to net types with initializer, modifier, source/receiver and priorities listed under each net type.

c. LIU state table: This table contains all the information on the state of each LIU in the FI. The contents of the table are discussed below.

1. Connect/Disconnect - Indicates whether or not the LIU is connected to the LI bus.
2. Operational/Nonoperational - Indicates if the LIU is capable of performing its functions to transfer data on the LI (operational) or if the LIU is not functioning properly (non-operational).

The LIU State Table will probably be listed according to LI and subdivided into LIU addresses.

4. Device status table: This table lists the operational status of every device serviced by the FI. The table will probably be constructed according to device virtual address, either in numerical sequence or according to some convenient grouping. Within a devices block in the table are listed every device network it is participating in. These networks most likely will be grouped by network type. The example in Table 5-6 shows device m's (VA=m) listing, starting with Direct Address (DA) nets. The first DA net (M) is then fully described as shown by the Net Descriptor entries on the right hand side of the table. The next DA net that device n is participating in (DA net: N) is described, and each DA net that the device is participating in. Then each virtual bus net that the device participates in is fully described in the same manner. After that, the Lazy Susan and Broadcast nets are described. When all of device m's net participation is fully described, then device n's net participation is then described, and so on until the status of every device serviced by the FI is listed.

TABLE 5-6 DEVICE STATUS TABLE

V. A. No: n
  Direct Address (DA) Nets
    DA net No: M
      Net Descriptor →
    DA Net No: N
    •
    •
    •
    DA Net No: Z
  Virtual Bus (VB) Nets
    VB Net No: N
    •
    •
    •
    VB Net No: Z
  Lazy Susan (LS) Nets
    •
    •
    •
  Broadcast (BC) Nets
    •
    •
V. A. No: n

Net n
Sync/Async
Priority
Function
  Source/Receiver
  Net Initilizer
  Net Modifier
Participating VAs
  Device 1-VA
  2
  •
  •
  •
  Device N-VA
Devices Response Algorithm

The entries under the net descriptor down to net modifier have already been previously discussed. It is not clear if the virtual address of every device on the net will serve a useful purpose in this table. It might be useful in DA type nets if a user might wish to see a listing of all his device nets. The same information will be contained in the Net Table. The devices response algorithm must be contained in this table because this is the only location in the FI where it is stored, except in the device and LIU. If the LIU loses its database, then the response algorithm must be loaded back into it when the LIU is reinitialized.

e. Network table: Each device network implemented on the FI is described in this table. The table will most probably be constructed according to net type. The parameters of each network within a net type will be listed probably in a numbered sequence. Table 5-7 illustrates how a network table might be structured. Under Direct Address nets, starting with DA Net #1, all its network parameters are listed in its net descriptor as shown on the right side of the table. In this table, each participating device must be listed according to its virtual address. The devices function on the net must also be listed according to its VA. The Net's sequence algorithm must also be stored with net's parameters. The algorithm is the description of each participating device's (LIUs) access to the net. No sequence algorithm is required for the direct address nets.

TABLE 5-7. NETWORK TABLE

Direct Address (DA) Nets

    DA Net: 1

        Net Descriptor →

    DA Net: 2

    •
    •
    •
    •
    •

DA Net: n

Virtual Bus (VB) Nets

    VB Net: 1

    •
    •
    •

    VB Net: n

Lazy Susan (LS) Nets

    •
    •
    •

Broadcast (BC) Nets

    FI Net

    LI BC Nets

Net Rate

Sync/Async

Priority

Participating VAs

    Device 1 VA

        Source/Receiver

        Net Initializer

        Net Modifier

    Device 2 VA

    Device N VA

Net Sequence Algorithm

f. EI Address table: This table identifies the address of each shelter (LI/EIU) with its appearance at the transponder, i.e., its physical address on the FI.
g. Error reporting: A list of the user device to notify if device header errors are detected at the LIU's. A listing of the number and rate of network header errors are detected on each LIU.
h. EI database: The EI database must be stored in the FI Manager's non-volitile memory in case of a failure in the EICU such that it loses its database and must be reinitialized.
i. LI database: The LI database must be stored in the FI Manager such that if any of the LI databases in the LICU is lost, the LICU can be reinitialized by the FI Manager and its database reloaded.

EI. The part of the system control area of the FI database which affects the EI is listed in Table 5-8. A part of the database is contained in the EICU and part in the EIU. The part stored in the EICU is listed below.

TABLE 5-8. EI DATABASE (SYSTEM CONTROL)

EICU	EIU
EI Polling Algorithm	EIU Transmit Time Out
EI Transmission Time Out Table	EIU Buffer Allocation Table
EI Maintenance/Reporting	Receive VB & LS Net Table
EI Diagnostic Control/Reporting	

a. EI polling algorithm: The algorithm which controls the EIU access polling sequence is stored in the EICU since it performs the EI polling function. The polling algorithm will be modified each time a device network is initialized, modified or terminated, which affects the packet transmission on the EI. Modification of the EI polling algorithm will be performed in the FI Manager since more complex processing would be required than the EICu processor should be require to perform.
b. EI transmission time out table: This table lists the maximum time period an EICU is allowed to transmit on its uplink before it must terminate its transmission. At the end of the EIU's timeout the EICU will switch the uplink commutators in the transponder off that uplink. A timeout period is listed for each EIU on the FI.
c. EI maintenance/reporting: The EI maintaining routines, which have not been studied yet, will be stored in this file along with the maintenance status of each EIU.
d. EI diagnostic/reporting: The EI Diagnostic and Fault Isolation Routines will be stored in this file along with the diagnostic and failure status of each EIU.

The part of the EI area of the database contained in the EIU is listed below.

a. EIU transmit time out period.
b. EIU buffer allocation table: The distribution of the buffer required for LI/EI data, between the LICU and the EIU. If the EIU buffer is sized for more than one packet then a buffer allocation table must be stored in each EIU. The table identifies the portion of buffer allocated to: VB, LS, Broadcast, and DA nets. Buffer space is dedicated for VB, LS, and Broadcast nets, while the remaining buffer space is allocated to DA nets.
c. Receive VB & LS net table: The EIU receiver acts as a packet filter by examining each network header and passing onto the LICU only the packets destined for the LI. To filter the VB and LS nets, a table of the nets which its resident LI is participating in must be part of the EIU database.

LI. The part of the system control area of the FI database which affects the LI data transfer is listed in Table 5-9. A part of the database is contained in the LICU and part in the LIU. The part stored in the LICU is listed below.

a. LI polling algorithm: The algorithm which controls the LIU access polling sequence is stored in the LICU since it performs the LI polling function. The polling algorithm will be modified each time a device network is initialized, modified or terminated, which affects the packet transmission on the LI. Modification of the LI polling algorithm will be performed in the FI Manager since more complex processing would be required than the LICU processor should be required to perform.
b. LI maintenace/reporting: The LI maintaining routines will be stored in this file along with the maintenance status of each LIU.
c. LI diagnostic/reporting: The EI diagnostic and fault isolation routines will be stored in this file along with the diagnostic and failure status of each LIU.
d. LIU state table: See FI Manager data base description.
e. LIU database: The LIU database must be stored in the LICU such that if any of the LIU's database is lost, it can be reinitialized and its database reloaded by the LICU.

The part of the LI area of the database contained in the LIU is listed below.

a. Device virtual address: The virtual address of the device the LIU is servicing. Used by the LIU in analyzing the deive header (see Section 5.3.3.2).

b. Device status table: This table, described earlier, is used by the LIU to determine if its device data transmission requests are valid, and in formatting a new network header for packet transmitted (see Section 5.3.3.2)

Once the data base is loaded for each subsystem and component, the FI system is ready to enter into the data transfer mode.

TABLE 5-9. LI DATABASE (SYSTEM CONTROL)

LICU	LIU
LI Polling Algrithm	Device Virtual Address
LI Maintenance/Reporting	Device Status Table
LI Diagnostic Control/Reporting	
LIU State Table	
LIU Database	

5.3.3 Data transfer mode. Once the system initialization processed is complete, the data transfer mode can begin. The system control functions operational during the data transmission mode which were studied during Task III are: Device Net Control, Data Transmission Protocols, System Error Control, and Failure Control. These control functions are discussed in the following sections.

5.3.3.1 Device network control. The exchange of data between devices on the Fi takes place via device nets which are dynamically configured on the FI. The establishment, modification and termination of these nets is performed under the control of the FI Manager, through the interaction between certain controlling devices and the FI Manager.

The mechanism by which data is transferred via a device net on the FI is the transmission of control (poll) and data packets on the LI and EI buses. The data transmit and receive function are described below.

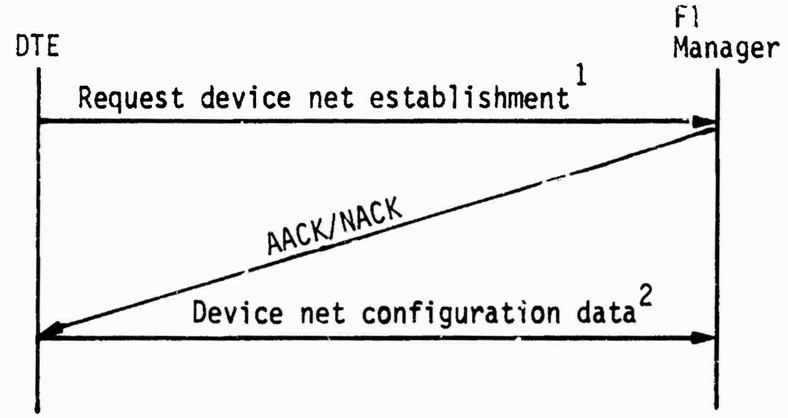
1. Data transmit - Access is provided to the data source (LIU) to transmit data by polling it and then allowing it to transmit its data packet on to the LI bus.
2. The LI polling algorithms are constructed such that the net is polled at a rate commensurate with its required data transfer rate, or in the case of a direct address net the participating LIUs are individually polled to provide the data sources access to the net.
3. Data receive - The LIUs monitor the LI bus and analyze each packet header to determine which network the data packet belongs to. For example, a virtual bus (VB) net is identified in the network header by the message type indicating the packet is a VB net and the net number indicating which VB net the packet is for. If the device recognizes that the VB net type and number correlates to a net it is on (net type and number stored in its device status table), it will transfer the data on the LI bus into its buffer and then pass it on to the device.

The device network configuration and transmission system controls are described below. The data transmission protocols are described in detail in Section 5.3.3.2., and the implementation in the LIU of the protocols for the various device network types are described in Section 5.3.3.2.

5.3.3.1.1 Configuration control. The control of the configuration of device nets is an interactive control function between selected user devices and the FI Manager, to allow adaptive configuration of the FI device network structure. This degree of freedom allows users to tailor the FI network structure to best serve the needs of each center individually, while maintaining a high degree of commonality in the functional operationals in the FI system. The three functions performed in the device net configuration control are; the establishment, modification and termination of the nets. Each function is described below.

Device net establishment. Certain users on the FI are allowed the privilege of controling networks involving a group of user devices assigned to them. A device allowed this privilege must send a message requesting the establishment of a new net (of a particular type) to the FI Manager. Figure 5-31 illustrates the exchange of control information required between the initializing DTE and the FI Manager in establishing a device net. The initializing DTE must first generate a full description of the net. The network descriptor data is listed in Table 5-10. This data is essentially the same as the data listed on the right hand side of Table 5-7. The entries are discussed in Section 5.3.2. The DTE must then formulate a message containing the request to establish a new net and the net description. It then sends the request message to the LI for transmission over a direct address net to the FI Manager. Assuming the device header is correct, the LIU then transmit a packet containing the request message to the FI Manger.

The FI Manager analyzes the request using its Device Identification Table (5-4), Device Option Table (5-5), Device Status Table (5-6) and the LIU State Table. If the request meets all the acceptance criteria, an AACK message is sent back to the DTE over a direct address link, if not, a NACK message is sent back to the DTE. The FI Manager then assigns a number to the net. It then formulates a command message for each device on the new net containing all the information required for the device to participate on the net. The information is listed in Table 5-11, and the entires are described in Section 5.3.2. The command messages are then sent to each device on the net. A similar command message is formulated and sent to each of the LIUs on the net. After each device and LIU on the net have been loaded with the new net data, the FI Manager formulates new polling algorithms for each LI affected and also the EI, if the net traverses the EI. It then transfers the new polling algorithms into the appropriate LICU's and EICU. When the polling algorithms are loaded, the new net will be automatically implemented. No further action is required on the part of the FI Manager or the initializing DTE.



Functions (DTE)

Decision to establish device net

Fully identify device net

Send device net establishment request & net description

1. Request message includes all device net characteristics
2. To each participating DTE

Functions (F1 Manager)

Analyze request

Make decision on establishing device net

Inform requesting DTE of decision (AACK/NACK)

Inform each affected DTE of its participation on the net and modify its data base to include the new net data

Figure 5-31. Device network configuration control.

TABLE 5-10. NETWORK DESCRIPTOR DATA GENERATED BY INITIALIZING DTE

Device Net Type
Net Rate
Priority
Participating DTEs (VA)
Source/Receiver
Net Modifier
Net Sequence Algorithm

TABLE 5-11. DEVICE NETWORK FUNCTION DATA

Net Type and Number
Source/Receiver
Net Initializer
Net Modifier
Other Devices (VAs) On Net
Device's Response Algorithm

Device net modification. Certain users identified in the Device Net Table, under the particular net type and number, as being allowed the privilege of modifying that particular net can do so. The modifying DTE must obtain from the FI Manager, a complete description of the net. The data is contained in the Network Table (5-7) listed under the particular net type and number. These request and response messages are transferred over a direct address link. The modifying DTE must then send a request message to modify the net, along with a complete description of the modified net to the FI Manager. The data is the same type as the data required for the net establishment except that the net type and number have already been assigned. The same procedure is followed as for net establishment except that existing tables are modified and only the devices and LIUs which are affected by the modification are changed by the FI Manager. The polling algorithms of the affected LIs and EI are also changed by the FI Manager.

Device net termination. An existing device net may be terminated by any device identified as a net modifier on the particular net to be terminated. The device need only send a net termination request message, identifying the net (type and number) to the FI Manager, over a direct address net. The FI Manager must make the decision to terminate the net. It then sends a AACK or NACK back to the requesting DTE. If it terminates the net, the FI Manager sends a response message to all affected devices, and LIUs. The polling algorithms of the affected LIs and EI, if required, are modified and sent to the appropriate LICUs and EICU. The terminated device net is then deleted from the Network Table, and the Device Status Table in both the FI Manager and affected LICUs.

5.3.3.1.2 System controls. The system control of the data transfer between devices on the FI manifests itself in how the FI subsystems operate to implement the device networks The control of the nets is implemented by the interoperation of several FI subsystems and the devices themselves, which actually implies several levels of control. The highest level on the LI is the LICU polling the device nets, and the LIU (direct address transmission). The second level of control is in the LIU, where it determines if it is to transmit devices data on the bus, by analyzing the net access algorithms and the network header information. To illustrate these controls the implementation of each type of device net will be described below. The operational requirements and description of the device nets appear in Section 4.2.

Direct address net. The direct address (DA) net requires the simplest system control since it provides only simplex, point-to-point transmission. The control mechanism is the LICU transmitting a DA poll message on the LI, with the polled LIU's address in the destination address field of the network header. The LIU recognizes that the poll message is directed to it by analyzing the poll packet header. It then responds with a DA poll response packet. If the LIU had already received a message from its DTE, it will transmit the message in the response packet. If not, it will transmit an idle packet in response to the poll. Each DA net is characterized by its transmission rate whether the DTE is synchronous or not. All dedicated point-to-point cable links in exsiting TAF centers will be replaced by DA nets.

Virtual bus net. The Virtual Bus (VB) net is actually the implementation of an ordered sequential access bus. Access to the bus is controlled by the LICU polling the VB net and the LIUs accessing the VB net time slots for transmission according to the net's sequential access algorithm. VB time slots, while not necessarily hemogeneously dispursed in time, occur at a nominal rate, i.e., the long term average of the VB time slots is equal to the nominal VB transmission rate. Messages always occur in a sequential basis, on the VB, i.e., message number n will always appear on the LI bus before message number n+1 is transmitted.

The data transmission rate (b/s) of the VB net is determined by two parameters:

a. Message length,
b. Nominal polling rate of the VB net.

A fixed length packet transmitted at a nominal packet rate (polling rate) yields a nominal bit rate for the net.

For VB nets, the LICU does not poll LIU's, as is the case for DA nets, but rather, polls the VB net. The network header in the poll packet contains the message type and number, which identifies a unique VB net. It also contains a VB sequence number which time sequence tags each time slot on the VB. Each LIU on the VB net is responsible for keeping a real time count of the sequence of the VB.

When the VB net is established, each participating device and LIU is assigned specific sequence numbers, identifying the VB time slots in which it must transmit a response packet. One method suggested by the government, of determining the LIU's VB access sequence numbers is to assign each DTE (LIU) a starting number in the sequence and a repetition rate. Using these two parameters, stored in its database, the LIU could very simply keep track of its next VB access sequence number. (Example: If a processor in the application system is assigned a sequence number 76 and a repetition rate of 64, then it will first be allowed to transmit on the VB at time slot 76 and another 64 transmissions later at time slot 140, and again at 204 and so on).

The implementation of a VB net (V.B.No:X) the FI is as follows:

- DTE with sequence no: n-1 sends a message to its LIU;
- LICU polls V.B.No:X;
- LIU with sequence No: n-1 transmits message onto the LI;
- All LIUs on V.B. No: X receive the message;
- LIUs send the message onto their respective DTEs;
- All LIUs on V.B. No: X increment the "Real Time" count for the VB;
- DTEs increment message number;
- DTE with sequence No: n sends its message to its LIU before VB. No: X is polled again;
- LICU polls VB. No: X again; and
- LIU with sequence No: n transmits the message onto the LI bus.

All LIUs on VB No: X will again receive the message and increment the "Real Time" count for the VB.

The LIU must always transmit a message onto the LI bus in its access sequence time slots. If it has not received a message from the DTE when the VB is polled, it must transmit an idle message in the time slot, such as to keep the VB sequence number (real count) incrementing. The idle message will probably be a short message consisting only of a network header.

Lazy susan net. The lazy susan (LS) bus is a ring structured bus in which the data moves from device to device on the ring. Each device on the ring, if given authority, is allowed to modify the data before passing it on the next device on the ring. When the LS net is established, a master is defined for the ring, and the participating devices are identified as to their place (sequence) on the ring. The device sequence is identified in the LIU database by defining the address of the LIU which proceeds it in the ring, i.e., the source of its data on the ring. The master starts the ring transmission and assigns message numbers to the data as it propagates around the ring.

The LS bus is implemented in essentially the same manner as the direct address net in that a device on the LS net transfers the data to the subsequent device on the net (point-to-point). The net is, however, identified as a lazy susan net in the message header so that the receiving device is informed that it can either modify the data or pass it on unchanged to the subsequent device on the LS net. The device is assigned a holding time when the net is established. The holding time is the time in which it is allowed to hold the data in order to modify it. If the device does not modify the data by the end of the holding time, the data must be passed onto the next device. This is implemented by making the LIU store the LS data. If no new data is received from the device by the time the LIU is polled for the LS net, the LIU will send the same data to the subsequent LIU in its poll response packet.

To insure the preservation of the LS net's data as it propagates around the ring, the LIU receiving the data from the transmitting LIU in the ring must guarantee buffer space is available to recieve the packet. If buffer space is not available, the data would be lost. The mechamism to provide the LS data transfer guarantee is a demand data function, which is somewhat like the reversal of a query/response. The LIU which is to receive the data sends a message to the LIU holding the data, telling it to send the data (implying that it has buffer space available). The receiving LIU checks the source address in the message header, and if it is the previous LIU in the ring (the one it is to receive data from) then it accepts the LS data. If not, it rejects it.

Devices may be allowed to monitor the LS bus, i.e., be receive only participants on the net. These devices are not in the ring path and as such they can not hold and modify the data as it propagates aroung the ring.

The net can be modified at any time to add a new device in the ring to perform a new process which was not anticipated when the LS net was established.

The number of participants on the LS nets are limited only by the source and destination address fields in the network header. The only rate limitations on LS nets is that it be no more than 20 Mb/s, and the maximum bandwidth of any single LS net be no more than 20 Mb/s. These are operational requirements imposed by RADC and is not a functional limitation of the FI system.

Broadcast net. Broadcast (BC) nets are established such that an authorized source may transmit a general message out to all devices identified as receivers on the net. There are two types of broadcast nets: one EI BC net and one LI BC net for each LI. When the BC nets are established, the devices which are receivers and possible message sources are identified. The broadcast net is not a continuously polled net. A device which is identified as a possible source must request to transmit on the BC net. It is then granted permission to transmit one message. The LICU then polls the source once (for the BC net) and the LIU responds by transferring the BC message onto the LI bus. If it is an EI BC net, the message is transmitted to all LIs via the EI. Once the message transmission is completed, the device must request permission before it can transmit again. Transmission control of the LI BC net should probably be under control of the LICU rather than the FI Manager, in order to give the LI net automnity from the EI in case of EI failure. It would also provide more transmission efficiency and reduce response time delay for BC nets.

5.3.3.2. Data transmission protocols. Protocols to control data transmission over the FI have been defined for all levels of communication. The overall view of data transmission control can be seen in Figure 5-32. The characteristics of data transmission on the FI can be described in both functional and operational terms.

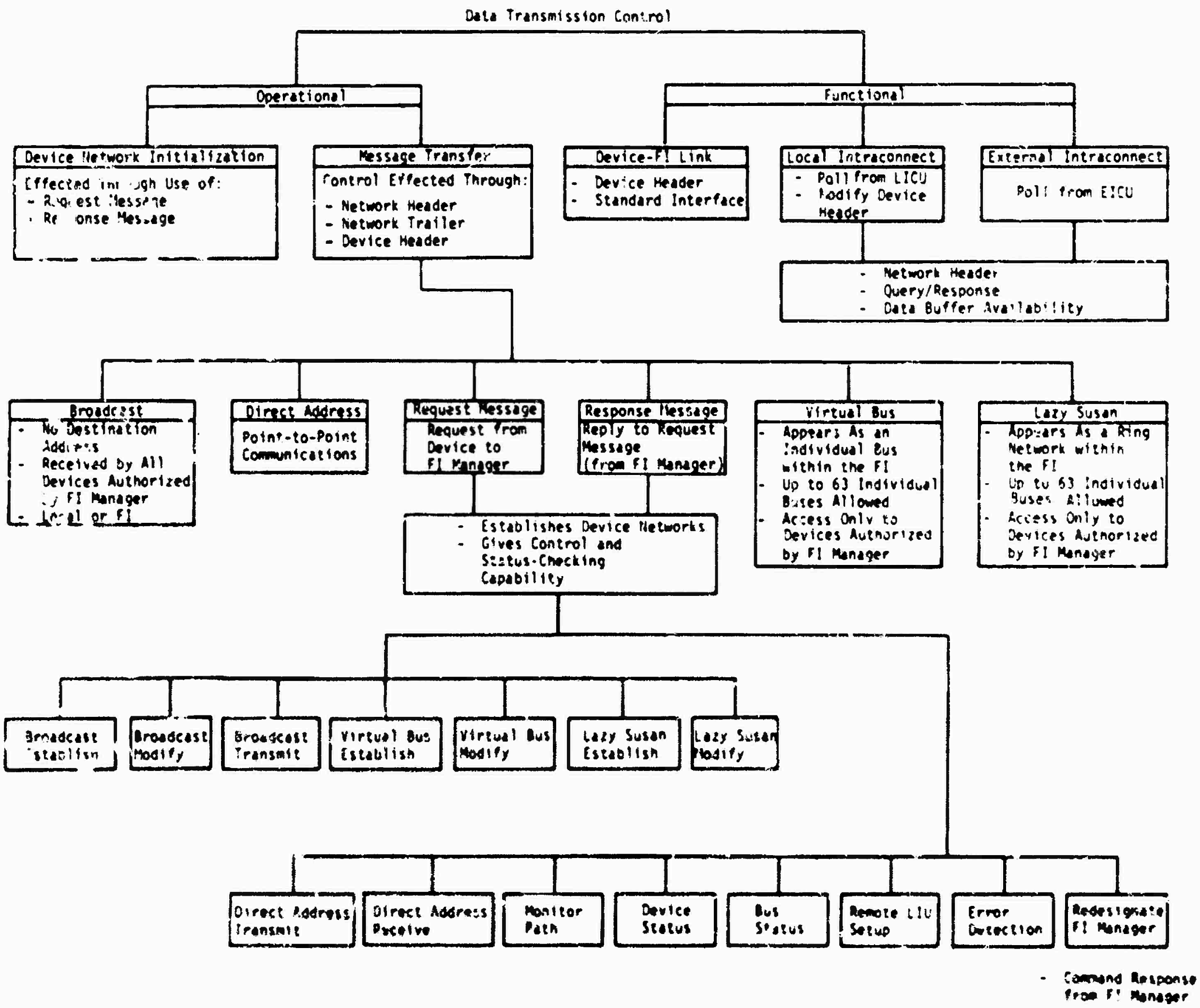


Figure 5-32. Data transmission control.

5.3.3.2.1 Functional Description.

5.3.3.2.1.1 FI levels of protocol. Figures 5-23 and -34 show the five different layers of protocol affecting data flow over the FI. The FI levels of protocol are not be be confused with or in any way related to the ANSI or ISO protocol models.

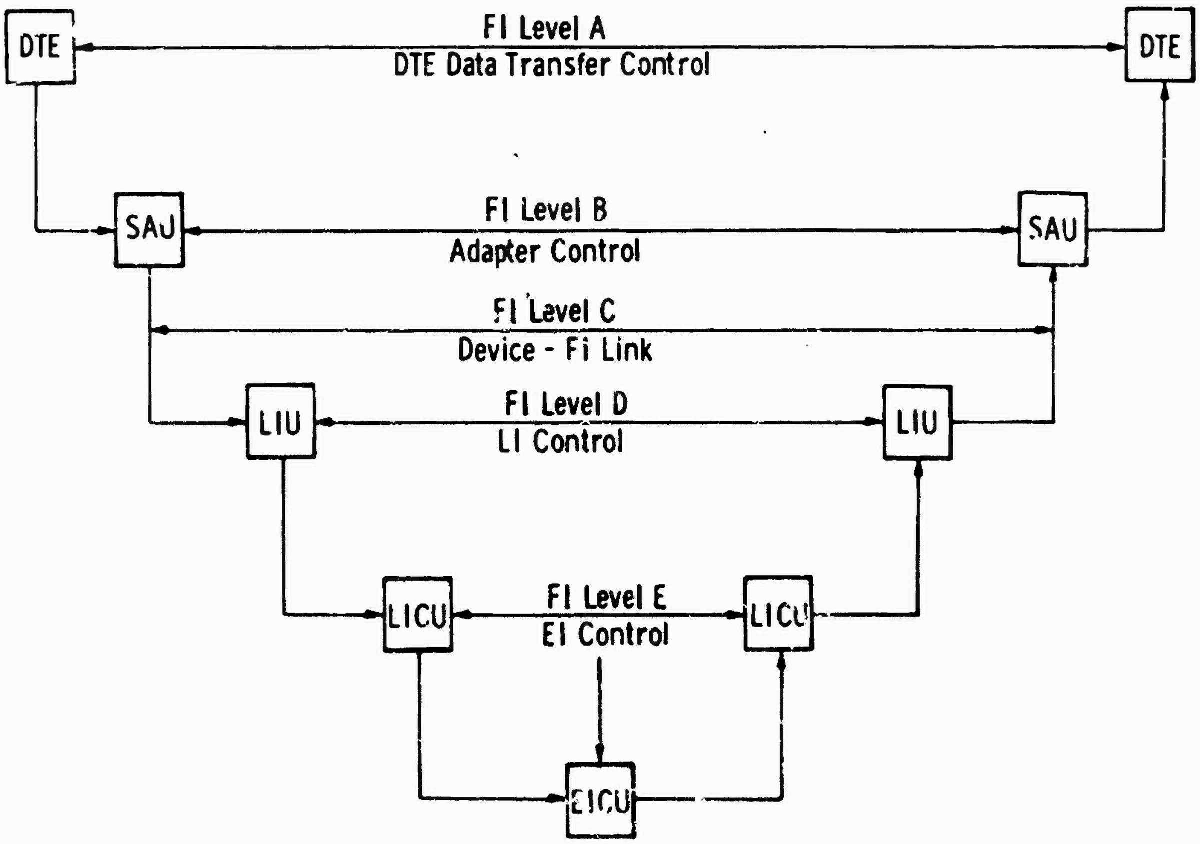


Figure 5-33. Levels of protocol.

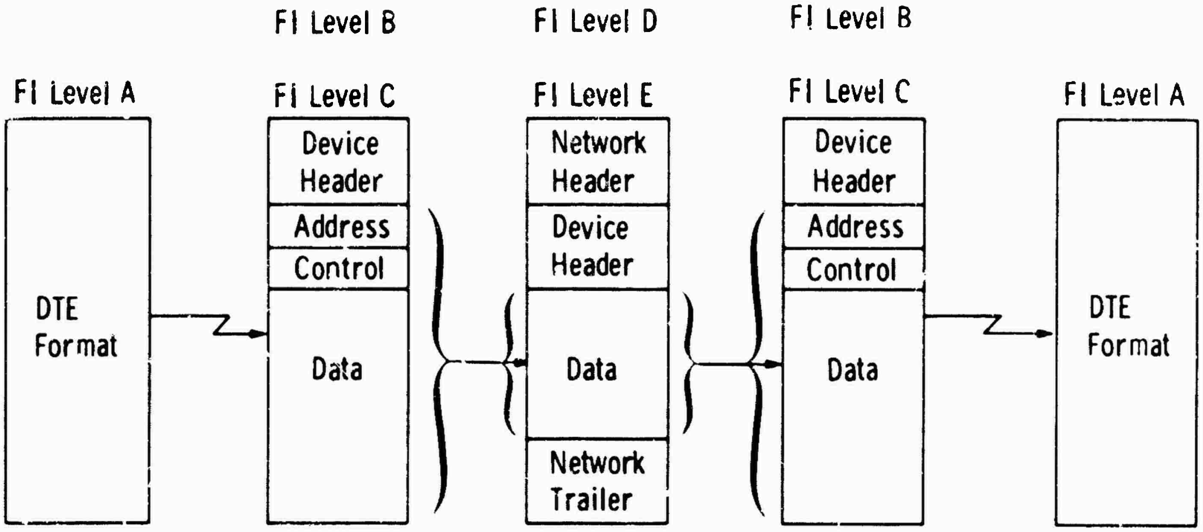


Figure 5-34. Formats at each FI level.

FI Level A concerns user-to-user protocol, i.e., process control. This data transfer control governs activities between devices as if they were directly connected.

FI Level B pertains to the formatting of address, control, and data to and from a DTE for interface to other DTEs. This protocol is mainly for control between adapters and would disappear when adapters are no longer needed.

The following three layers of protocol combine to perform end-to-end data transmission between users on the FI. They are unique to the FI and are the subject of the rest of this section.

FI Level C concerns the data link between a DTE or SAU and the FI. Control information for operation on the FI is contained in a device header which is attached to a block of data by the DTE or SAU. The actual transfer of header and data is accomplished according to the standard interface defined by RADC*.

FI Level D consists of the LI control. A network header and trailer are added to the device header and data block by the LIU. This provides information required to control LIU-LIU and LIU-LICU data transfers.

*MIL-STD-XXXX, "Flexible Intraconnect Hardware and Software Input/Output Interfaces," January, 1979, Rome Air Development Center (AF-SC), Griffiss AFB, N.Y. 13441.

Data transfer on the EI continues using the network header and trailer formulated at FI Level D. However, communication between the EICU and EIUs is required to configure the FI into a proper mode of operation. This warrants a separate layer of protocol - FI Level E - which pertains to the EI control.

FI Levels D and E are transparent to the user.

5.2.3.1.2 Data transfer scenario. Referring to Figure 5-35, an attempt by DTE1 to transfer data to DTE2 will be described to provide a better understanding of the mechanics involved in communication on the FI. The functional flow is depicted in Figure 5-36.

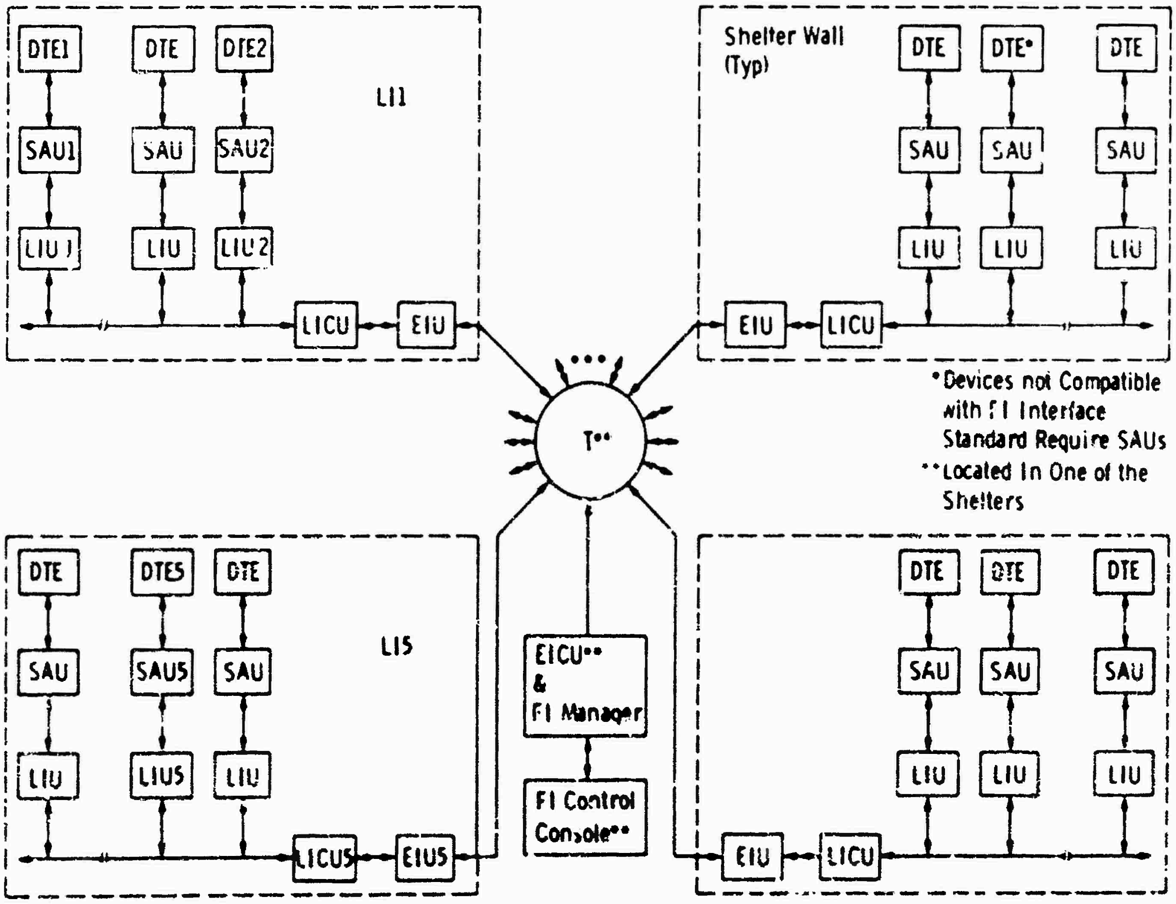


Figure 5-35. Flexible intraconnect configuration.

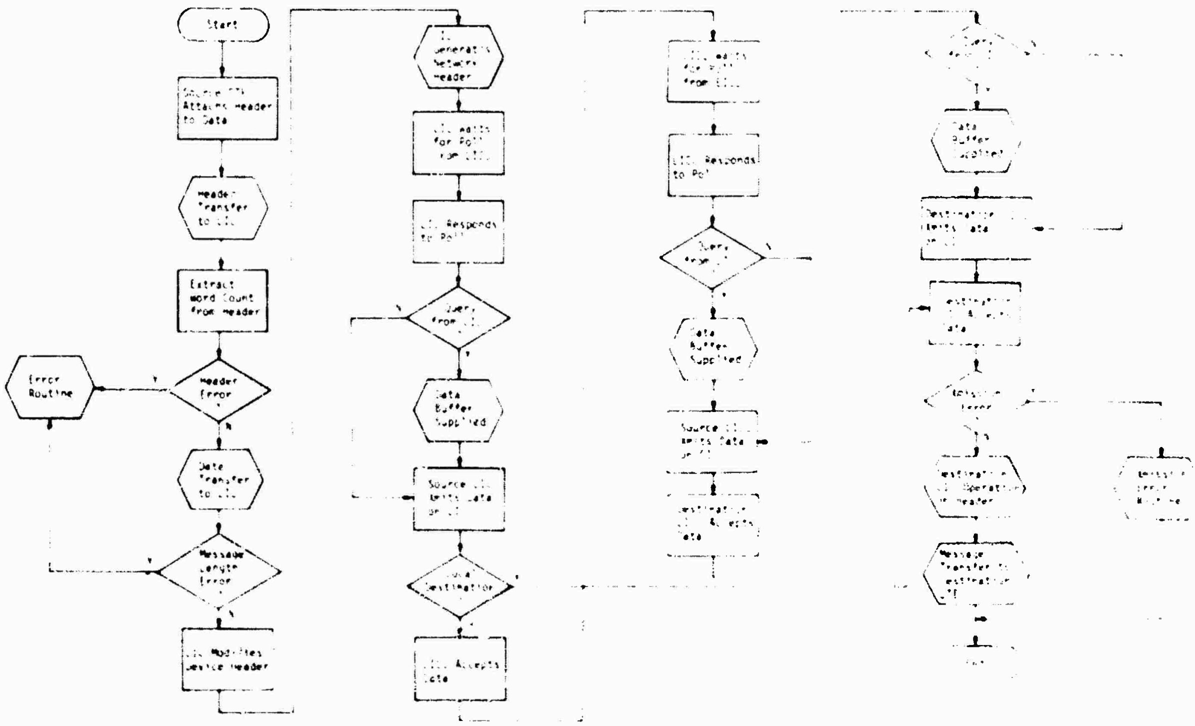


Figure 5-36. Device attempts data transfer.

5.3.3.2.1.2.1 Device - FI Link. A DTE wishing to transmit data on the FI (in this case, DTE1) must attach a device header to the block of data. This header (described in Section 5.3.3.2.1.3) provides control information required for DTE-DTE operation. The transfer of this header and data between the DTE and LIU is accomplished according to the interface standard. For present-day DTEs, an SAU may be required for interface to the LIU. The DTE would transmit the data to the SAU as if directly connected to the destination DTE (in this case, DTE2 or DTE5). The adapter, in turn, would structure this data for transmission to the LIU in accordance with the interface standard.

The header is transmitted to the LIU in DMA fashion with the block length always equal to sixteen 18-bit words. Transfer of the data field to the LIU is delayed until the LIU extracts the word count to determine the block length of the data field, checks if the virtual address is valid, and tests the header for vertical parity errors.

If an error is detected, the LIU formulates an error message to be transmitted to the FI Manager. If no error is detected, the rest of the message block, i.e., the data field, is transferred from the DTE to the LIU in DMA fashion. Three events must occur at the end of the data transfer: 1) the

proper sign-off procedure as described in the interface standard should take place between the LIU and DTE/SAU; 2) the Input Data Request (IDR) line should go inactive; and 3) the number of data words transferred should compare to be equal to the message word count which was previously extracted from the device header. If an error is found in any of these events, an error message is formulated and sent to the FI Manager. If no error is detected, the LIU modifies the device header by attaching a parity bit to each 8-bit byte, adding a date-time group, and changing the vertical parity to reflect these additions. The LIU also generates a network header for control of data transmission between FI components, e.g., LIU, LICU. This header is attached to the data packet as described in Section 5.3.3.2.1.3.

5.3.3.2.1.2.2 Local intraconnect. The data packet is held by the transmitting LIU (LIU1) until a poll is received from the LICU (LICU1), which is continually polling all devices on its bus. The poll message sent from the LICU is stored in a buffer in each LIU until an accept/reject decision is made by the LIU, i.e., the LIU decides if the message is intended for it.

After accepting the poll message from the LICU, the LIU must respond with a message indicating if it has data ready for transmission. If not, the LICU continues to poll the other LIUs on its bus. The LIUs response to the poll depends on the type of message it is transmitting. If the message is a broadcast, a lazy susan, or for a virtual bus, the entire data block is transmitted on the LI by LIU1. Any other message type requires a query (as described in Section 5.3.3.2.1.3) from LIU1 as to the availability of buffer space large enough to hold the data packet at the immediate destination (LIU for local traffic or LICU for external). As demonstrated in Figure 5-37, if the buffer is not available, the destination stores LIU1s address in a queue (if not previously stored), then notifies LIU1 of the buffer nonavailability. The purpose of storing the source's address is to assure that later-polled LIUs will not gain access to the same destination before LIU1. Buffer space will be allocated by the destination to LIU1 according to its position in the stack. Meanwhile, the LICU will continue polling to expedite traffic on the bus. LIU1 will transmit data to the destination LIU or LICU once it receives a poll after buffer space becomes available.

If the destination is a DTE on the same bus (in this case, DTE2), its associated LIU will store the message in one of its buffers. This LIU (LIU2) will then check the network header for parity errors, vertical and horizontal, and verify the number of header words. Error checking will also be done on the data portion of the message block. If an error is detected in the network header, an error message is formulated by LIU2 to be sent to the FI manager. Error checking will also be done on the rest of the message block (device header and data). If an error is detected here, LIU2 will formulate a message notifying DTE2 of the error. If the transmission is error-free, LIU2 will extract the message length from the device header to set up the DMA transfer of the data to DTE2. The device header and data is transmitted to DTE2 in a DMA fashion according to the standard interface.

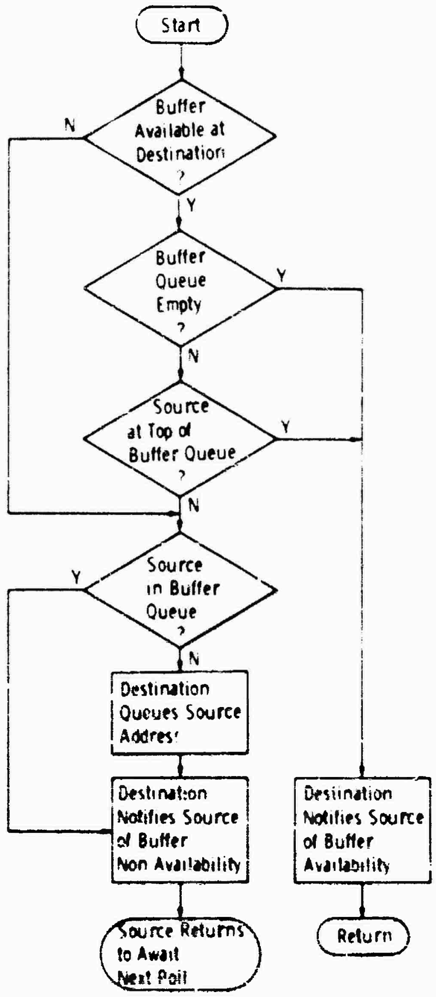


Figure 5-37. Determine buffer availability.

5.3.3.2.1.2.3 External intraconnect. If the destination is a DTE on a different LI, such as in a separate shelter (in this case, DTE5) LICU1 will hold the message block until a buffer is available in EIU1. LICU1 then transfers the data to EIU1 in DMA fashion according to the interface standard. EIU1 will hold the message packet until it is polled by the EICU. The response by EIU1 to the poll depends on the type of message it is transmitting. If the message is broadcast, lazy susan, or for a virtual bus, the entire data packet is transmitted on the FI by EIU1. All other message types require a query from EIU1 as to the availability of buffer space large enough to hold the data at the destination EIU (EIU5). If buffer space is unavailable, EIU5 stores EIU1s address in a queue (unless previously stored), then notifies EIU1 of the buffer non-availability. As in the case of the LIUs, EIU1 will be allocated buffer space in EIU5 according to its position in the queue. The EICU will continue to poll the other EIUs in the network. EIU1 will transmit data to EIU5 upon receiving a poll after buffer space becomes available. Upon acceptance of the message, EIU5 will transmit the data packet to LICU5

when buffer becomes available in LICU5. The data is transferred from EIU5 to LICU5 in DMA fashion according to the interface standard. LICU5 will then transmit the message block (if broadcast, lazy susan, or for a virtual bus) or a query as to the availability of buffer space in the destination LIU (LIU5). Buffer nonavailability is treated as previously described - queuing of LICU5's address in LIU5, notification to LICU5, and waiting for buffer availability before transmission of the message from LICU5 to LIU5. Upon acceptance of the data packet, LIU5 checks for transmission errors as previously described for LIU2. Again, if an error is found, an error message is formulated by LIU5 and sent to the FI Manager and/or DTE5. Otherwise, LIU5 will set up the DMA transfer mode to DTE5 and transmit the device header and data according to the interface standard.

5.3.3.2.1.3 FI message format. Messages transmitted on the FI are to be formatted with a (1) network header, (2) device header, (3) data, and (4) network trailer as shown in Figure 5-38.

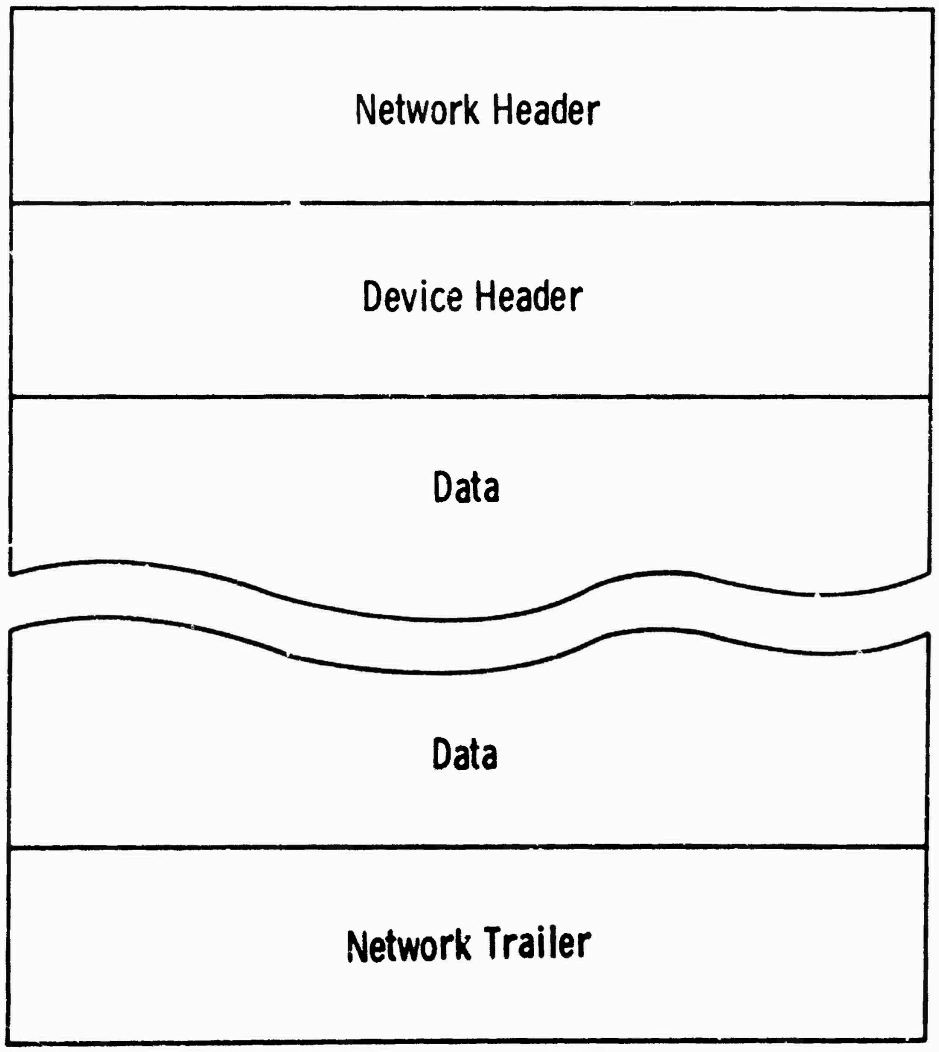


Figure 5-38. FI message format.

Network Header and Trailer. The network header consists of up to five 36-bit words attached to the body of the message as shown in Figure 5-39 and defined in Table 5-12. The network trailer is a 36-bit word designating termination of the message and/or transmission and is appended to the end of the message. The network header and trailer provide control information for transmission of data on the FI. They are for use on the LIU/LICU level and are transparent to the DTE. The network header and trailer fields are arranged for 8-bit processing convenience and for ease of growth.

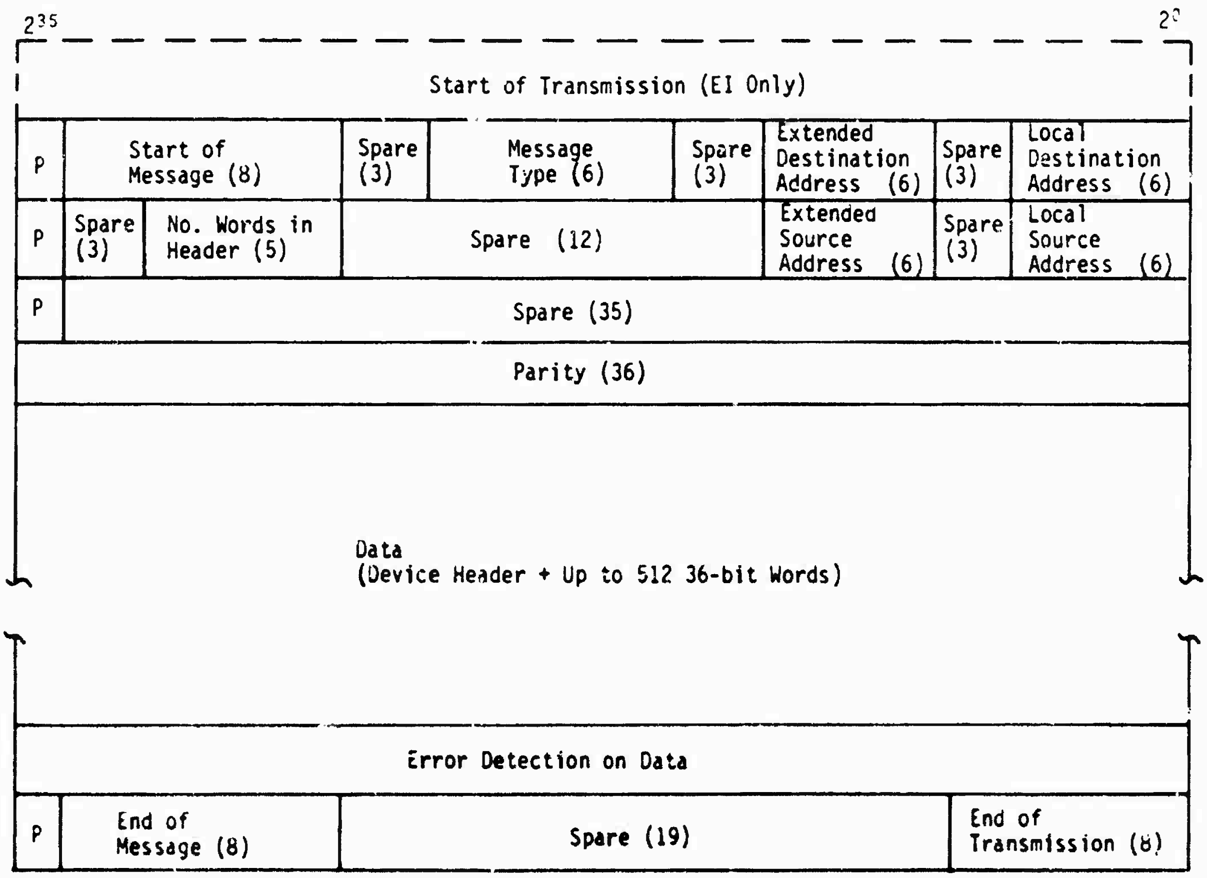


Figure 5-39. Network message format.

To transfer data on the EI, a "Start of Transmission" word (SOT) must precede the header to indicate that data is following. This SOT is to be transmitted unencrypted with the rest of the block encrypted. To avoid compromise of the security of later transmissions, the bit pattern of the SOT would be modified for each transmission. To accomplish this on the FI, the SOT bit pattern for the next transmission will be part of the network header of the preceding message, that is, the SOT for message n will be part of the header for message n-1. This serves to alert the destination EIU of the SOT bit pattern which should precede the next transmission. As indicated in Figure 5-39, the SOT is appended to the network header by the source EIU for traffic on the EI only, not the LI.

TABLE 5-12. NETWORK MESSAGE FORMAT

Field	Description
Start of Transmission	Indicates bit pattern to precede next transmission on EI only.
P	Horizontal odd parity bit (MSB) for each 35-bit word.
Start of Message	Unique character identifying start of message.
Message Type	Indicates network message type. Twelve are currently identified.
Spare	Spare bits.
Extended Destination Address	Indicates real address of the receiving LICU.
Spare	Spare bits.
Local Destination Address	Indicates real address of the receiving LIU.
No. Words in Header	Indicates number of 36-bit words in the network header.
Spare	Spare bits which may be used as device diagnostics information for implementation of loopback test.
Extended Source Address	Indicates real address of the transmitting LICU.
Spare	Spare bits.
Local Source Address	Indicates real address of the transmitting LIU.
Spare	Additional 35-bit word for expansion.
Parity	Vertical parity on the network header for error detection.
Data	Data field consists of device header (8 36-bit words) plus up to 512 36-bit device data words.
Error Detection	Vertical parity on data field for error detection.
End of Message	Unique character identifying end of network message.
End of Transmission	Unique character indicating more messages to follow or end of transmission.
Spare	Additional bits for expansion and/or further error detection.

Figures 5-40 through 5-43 describe formats for currently defined message types transferred on the FI with corresponding tables (5-13 thru 5-16)to describe the difference in fields. The message types include those defined for the device level (FI Level C), i.e., direct address, broadcast, virtual bus, lazy susan, request and response messages, as well as those required for network transmission (FI Levels D and E), i.e., poll, poll response, query response, and data transfer.

2^{35} 2^{0}

<table>
<tr><td colspan="9">Start of Transmission (EI Only)</td></tr>
<tr><td>P</td><td colspan="2">Start of Message (8)</td><td>Spare (3)</td><td>Message Type (6)</td><td>Spare (3)</td><td>Extended Destination Address (6)</td><td>Spare (3)</td><td>Local Destination Address (6)</td></tr>
<tr><td>P</td><td>Spare (3)</td><td>No. of Words (5)</td><td colspan="3">Spare (12)</td><td>Not Used (6)</td><td>Spare (3)</td><td>Not Used (6)</td></tr>
<tr><td colspan="9">Parity (36)</td></tr>
<tr><td>P</td><td colspan="2">End of Message (8)</td><td colspan="4">Spare (19)</td><td colspan="2">End of Transmission (8)</td></tr>
</table>

Figure 5-40. Poll.

TABLE 5-13. POLL

Field	Description	
<u>Message Type</u>	<u>Poll Identifier</u>	<u>Message Identifier</u>
Direct Address	000	001
Virtual Bus	000	010
Lazy Susan	000	011
Local Braodcast	000	100
FI Broadcast	000	101
<u>Destination Address</u>		
Direct Address	LIU Address	
Virtual Bus	Virtual Bus No.	
Lazy Susan	Lazy Susan No.	
Local Broadcast	Not Used	
FI Broadcast	Not Used	

2^{35} 2^{0}

<table>
<tr><td colspan="9">Start of Transmission (EI Only)</td></tr>
<tr><td>P</td><td colspan="2">Start of Message (8)</td><td>Spare (3)</td><td>Message Type (6)</td><td>Spare (3)</td><td>Extended Destination Address (6)</td><td>Spare (3)</td><td>Local Destination Address (6)</td></tr>
<tr><td>P</td><td>Spare (3)</td><td>No. of Words (5)</td><td colspan="3">Spare (12)</td><td>Extended Source Address (6)</td><td>Spare (3)</td><td>Local Source Address (6)</td></tr>
<tr><td colspan="9">Parity (36)</td></tr>
<tr><td>P</td><td colspan="2">End of Message (8)</td><td colspan="4">Spare (19)</td><td colspan="2">End of Transmission (8)</td></tr>
</table>

FIGURE 5-41 Poll.

TABLE 5-14. POLL RESPONSE

Field	Description	
<u>Message Type</u>	<u>Poll Response Identifier</u>	<u>Message Identifier</u>
No Data Available	010	001
Query	010	010
Lazy Susan Buffer Available	010	011
Data Transfer	011	(See Separate Format)
<u>Destination Address</u>		
No Data Available	LICU Address	
Query	Destination LIU Address	
Lazy Susan	Lazy Susan No.	
Data Transfer	(See Separate Format)	

2^{35} 2^{0}

<table>
<tr><td colspan="10">Start of Transmission (EI Only)</td></tr>
<tr><td>P</td><td colspan="2">Start of Message (8)</td><td>Spare (3)</td><td>Message Type (6)</td><td>Spare (3)</td><td>Extended Destination Address (6)</td><td colspan="2">Spare (3)</td><td>Local Destination Address (6)</td></tr>
<tr><td>P</td><td>Spare (3)</td><td>No. of Words (5)</td><td colspan="3">Spare (12)</td><td>Extended Source Address (6)</td><td colspan="2">Spare (3)</td><td>Local Source Address (6)</td></tr>
<tr><td colspan="10">Parity (36)</td></tr>
<tr><td>P</td><td colspan="2">End of Message (8)</td><td colspan="5">Spare (19)</td><td colspan="2">End of Transmission (8)</td></tr>
</table>

Figure 5-42. Query response.

TABLE 5-15. QUERY RESPONSE

Message Type	Query Response Identifier	Message Identifier
Buffer Available	100	001
Buffer Unavailable	100	010

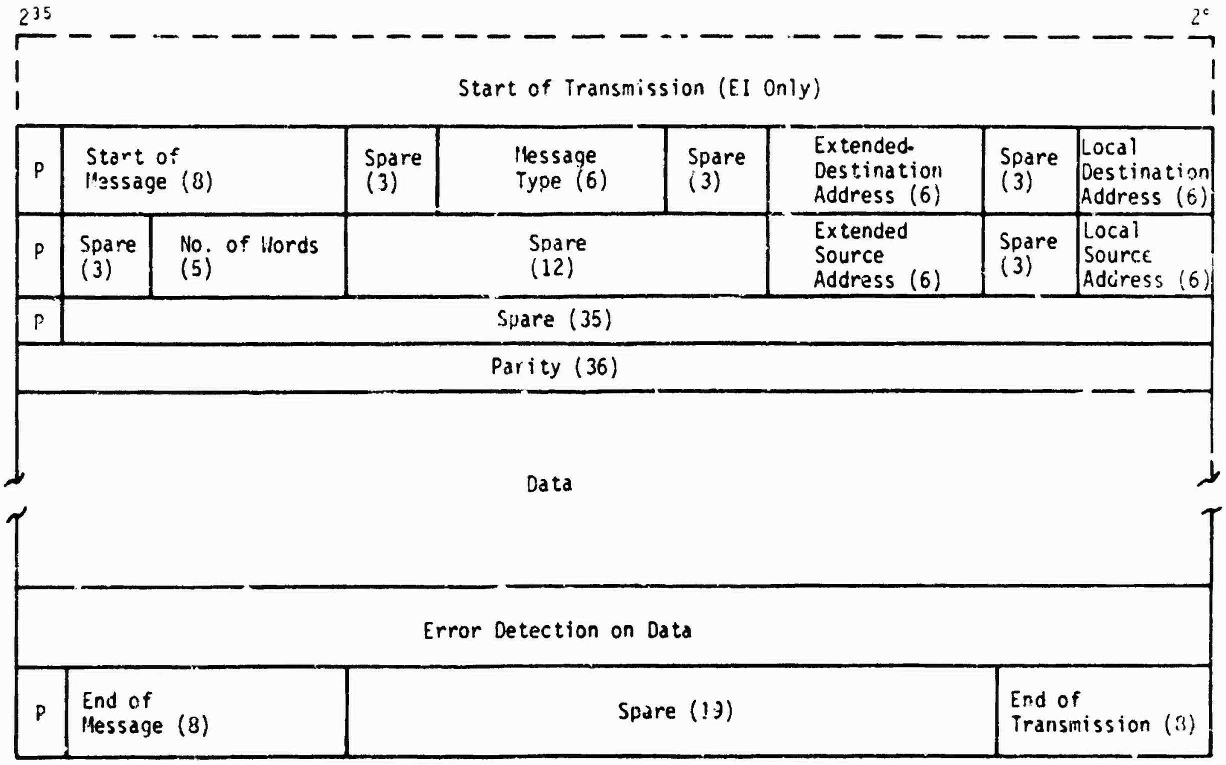


Figure 5-43. Data transfer.

TABLE 5-16. DATA TRANSFER

Field	Description	
<u>Message type</u>	<u>Data Transfer Identifier</u>	<u>Message Identifier</u>
Direct Address	011	001
Virtual Bus	011	[illegible]
Lazy Susan	011	011
Local Broadcast	011	100
FI Broadcast	011	101
<u>Destination Address</u>		
Direct Address	Destination of LIU Address	
Virtual Bus	Virtual Bus No.	
Lazy Susan	Lazy Susan No.	
Local Broadcast	Not Used	
FI Broadcast	Not Used	
<u>Source Address</u>		
Direct Address	Source LIU Address	
Virtual Bus	Not Used	
Lazy Susan	Source LIU Address	
Local Broadcast	Not Used	
FI Broadcast	Not Used	

The network headers for control on the EI are the same as on an LI. The same message type codes can be used for EI transmissions as well as LI since the control messages such as polls, poll responses, and queries are local to the LI or EI while end-to-end messages like data transfers contain the same header throughout the network. For instance, referring back to Figure 5-35, a data packet sent from DTE1 to DTE5 contains the same network header throughout (with only the addition of SOT for transfer between EIUs). Polls, queries, and responses on LI1 are unique to LI1 and the polls, queries, and responses between the EICU and the EIUs are unique to themselves (and the same with LI5). The LICUs and LIUs handle these control messages on the LI level while the EIUs and EICU handle them on the EI level. Because these activities are divorced from each other (may even run concurrently), the same codes for message types may be used for both LI and EI activities.

The only difference between control messages on the LI and EI, other than the addition of SOT, may be that the EI does not need the local addresses in the network header since communication between the EICU and the EIUs require only the extended address.

Device header. The device header is attached to the data transmitted by the DTE and consists of sixteen 18-bit words as shown in Figure 5-44 and defined in Table 5-17. This device header is added to the data packet in the DTE or SAU, then transmitted to the LIU according to the interface standard. This header provides control information which allows DTEs to communicate via the FI (FI Level C).

2^{17} ... 2^{0}

P	System Mode (3) / Message Type (4) / ACK/NAK (1)	P	Virtual Bus or Lazy Susan No. (6) / Priority (2)
P	X / R/V / Destination Extended Address (6)	P	XX / Destination Local Address (6)
P	X / R/V / Source Extended Address (6)	P	XX / Source Local Address (6)
P	Message Length (8)	P	Msg Length (3) / 1/2 Word / No. of bits (4)
P	Message Number (8)	P	Message Number (8)
P	Not Used (8)	P	Not Used (4) / DTG (4)
P	Date/Time Group (8)	P	DTG (8)
P	DTG (8)	P	DTG (8)
P	DTG (8)	P	DTG (8)
P	Not Used (8)	P	Not Used (8)
P	Not Used (8)	P	Not Used (8)
P	Not Used (8)	P	Not Used (8)
P	Not Used (8)	P	Not Used (8)
P	Not Used (8)	P	Not Used (8)
P	Not Used (8)	P	Not Used (8)
Parity (18)			

Figure 5-44. Device (DTE) header.

TABLE 5-17. DEVICE (DTE) HEADER

Field	Description
P	Horizontal odd parity bit for each 8-bit byte; generated by LIU.
System Mode	000 designates present mode of operation on FI.
Message Type	Indicates if message is request message, response message, direct address, virtual bus, lazy susan, or local or FI broadcast.
ACK/NAK	Indicates if acknowledgement for receipt of message is required from receiving LIU.
X	Unassigned bits; set to zero by LIU.
Virtual Bus or Lazy Susan No.	Designates virtual bus or lazy susan loop.
Priority	Indicates message priority with 00 as lowest and 11 as highest.
R/V	Indicates if address is real or virtual
Destination Address	Indicates FI address of receiving device; not used for broadcast, virtual bus, or lazy susan.
Source Address	Indicates FI address of transmitting device.
Message Length	Number of full data words in this block.
1/2 Word	Indicates if last data word is half word or full.
No. of Bits	Number of unused bits in last half word of data.
Message Number	Modulo 16 number added to each message by the transmitting LIU.
Data/Time Group	Data/Time in microseconds added by LIU when block is transmitted.
Parity	Vertical parity on the device header for error detection.

5.3.3.2.2 Operational description. Transfer of data on the FI can be categorized as a (1) control data exchange or a (2) message transfer.

5.3.3.2.2.1 Control data exchange. For the purpose of this discussion, a device network is defined as a method of communication between devices on the FI. A device network can take the form of a broadcast, virtual bus, lazy susan, or direct address.

5.3.3.2.2.1.1 Request/response messages. An exchange of control information must take place between a DTE and the FI Manager in order to establish the various conditions for communication on the FI.

If a device network is to be initialized or a DTE wishes access to a device network (or whatever other function is desired), a request message should be sent from the requesting DTE and/or LIU to the FI Manager. Its purpose is to seek establishment of device network initialization and access permission, request device or bus status, inform of errors, and other control functions originating with the device and/or LIU. The FI Manager, in turn, must reply with a response message to the requesting DTE and/or LIU. Other purposes served by a response message is to check device or bus status, direct modifications in device status, and other control functions originating with the FI Manager.

Table 5-18 lists the various types of request messages that are currently defined along with the type of information that should be contained within each request type.

TABLE 5-18. REQUEST MESSAGES

Function	Description	Information Required
Broadcast Establish	Requests permission to establish a broadcast network.	LI or FI broadcast; real or non-real time messages/s, message size list of users.
Broadcast Modify	Request permission to modify a broadcast network.	Data given in Broadcast Establish which is to be changed.
Broadcast Transmit	Requests permission to transmit broadcast messages.	LI or FI broadcast.
Virtual Bus Establish	Requests permission to establish a virtual bus.	Real or non-real time; messages/s; message size; list of users, sequence number and repetition rate for each user.
Virtual Bus Modify	Requests permission to modify a virtual bus.	Virtual bus number, data given in Virtual Bus Establish, which is to be changed.
Lazy Susan Establish	Requests permission to establish a lazy susan loop	Messages/s, message size; list of users and sequence of operation.
Lazy Susan Modify	Requests permission to modify a lazy susan loop.	Lazy Susan number, data given in Lazy Susan Establish, which is to be changed
Direct Address Transmit	Requests permission to transmit directly to a given destination.	Transmit only or transmit and receive; real or non-real time, messages/s message size, destination address
Direct Address Receive	Requests permission to receive directly from a given source.	Source address.
Monitor Path	Requests permission to monitor data flowing on a transmission path.	Transmission path description, e.g., source address, virtual bus number, lazy susan number
Device Status	Requests the status of a given device from the FI manager.	Device address.
Bus Status	Requests available status data of a bus or the FI.	LI or entire FI.
Remote LIU Setup	Requests the FI manager to provide a remote LIU (usually one connected to a receive-only device) with the necessary header to maintain communications between the FI manager and remote LIU.	Message size; remote LIU address; header.
Error Detection	Notifies the FI manager of an error situation.	Error type, location of error.

5.3.3.2.2.1.2 Device network initialization. For a device to operate on the FI, the proper device network must be set up. For instance, if the device is to communicate on Virtual Bus #47, then Virtual Bus #47 must be in operation and the device must have permission from the FI Manager to communicate on it. Authorization is required to receive as well as transmit, i.e., a device may have permission to transmit but if it desires to receive, it needs a separate authorization for this. These requirements also pertain to broadcast, lazy susan, and direct address.

Figure 5-45 demonstrates the operational flow of initializing device network, while figure 5-46 shows a device seeking permission to operate on a device network. To initialize a device network, an authorized DTE must send a request message to the FI Manager requesting establishment of the device network. The FI Manager replies with a response message establishing or disallowing the device network. If disallowed, the matter is resolved and the DTE is not allowed to communicate in such a manner. If the device network is established, any DTE wishing to communicate on it must send a request message to the FI Manager requesting permission to transmit or receive on it, or both.

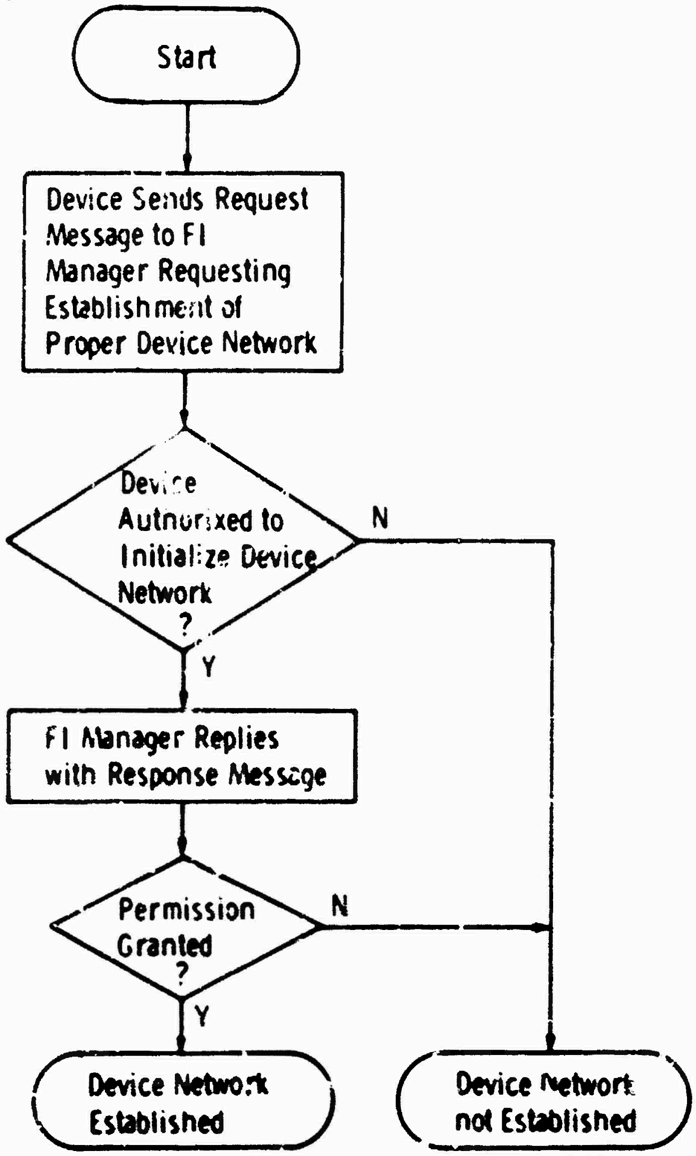


Figure 5-65. Device network initialization.

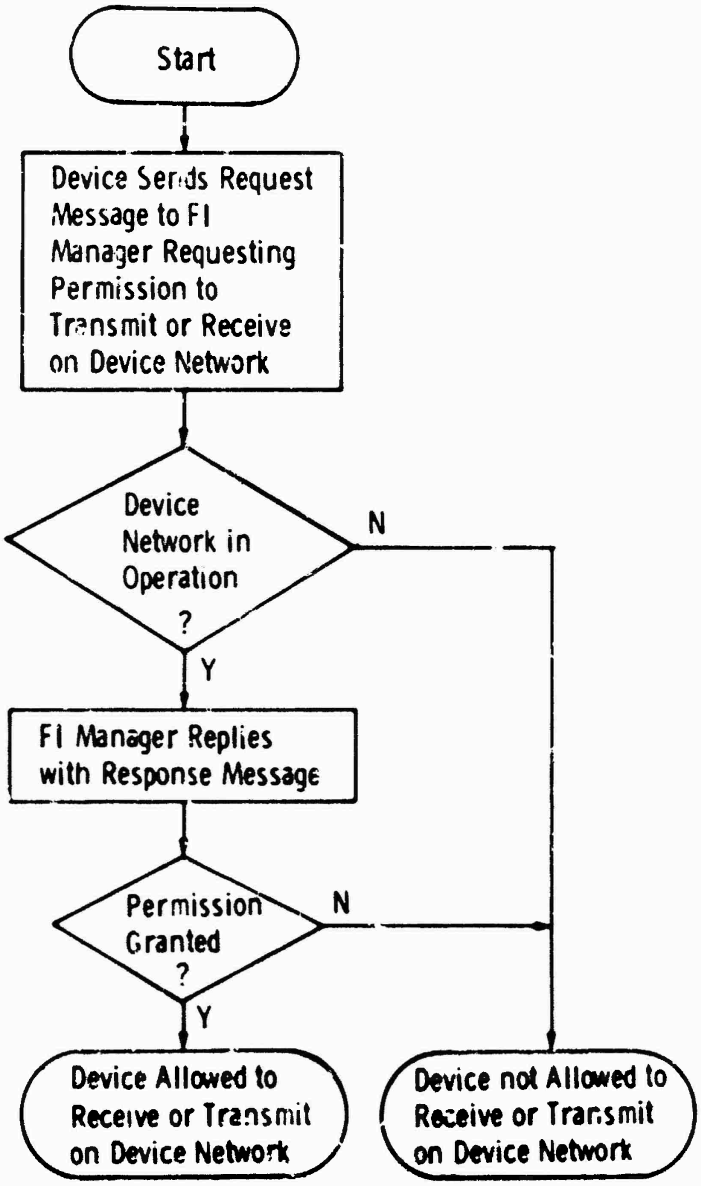


Figure 5-46. Authorization to communicate on device network.

The FI Manager replies with a response message which grants permission or not. If not, the DTE is not allowed to communicate in such a manner. If granted, the DTE can either receive or transmit accordingly.

5.3.3.2.2.2 Message transfer. Transmission of a message on the FI is controlled via the network header, network trailer, and the device header which are described in Section 5.3.3.2.1.3.

Once the proper device network has been set up and the necessary DTEs are authorized to communicate, a message can be transmitted over the FI as depicted in Figure 5-47. Control data for the transfer is contained in the device header which is attached to the block of data by the transmitting DTE or SAU. An important part of the control information lies in the message-type field of the header.

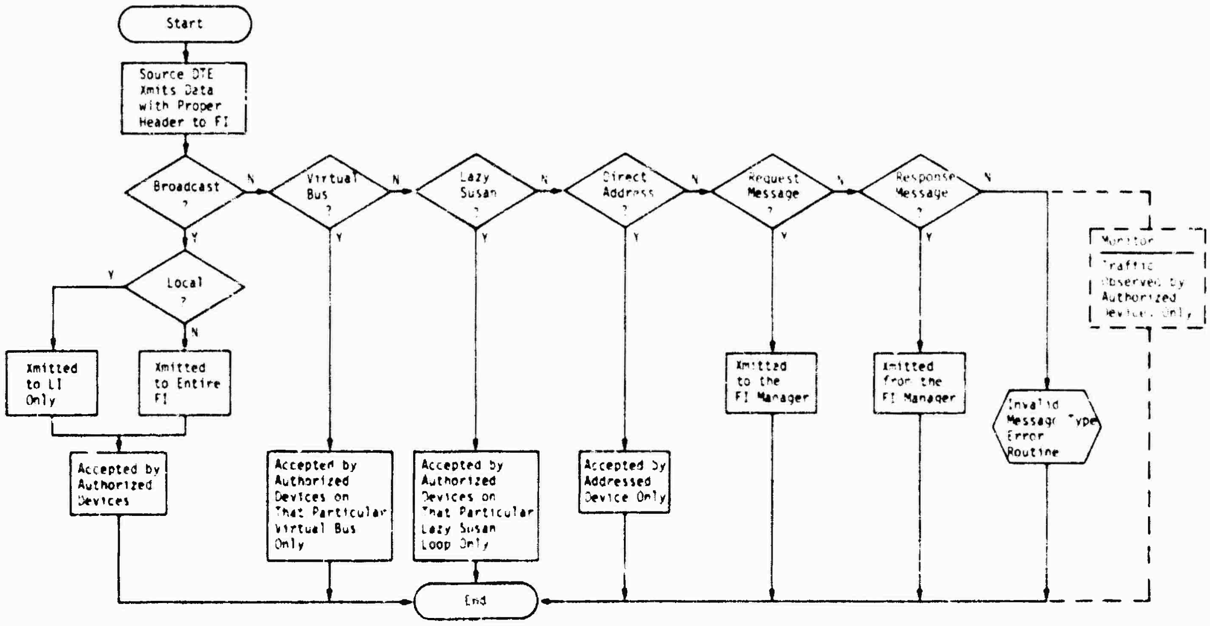


Figure 5-47. Message transfer flow.

A broadcast message is classified as either being for devices on the LI only or for the entire FI. Only devices that have previously been authorized by the FI Manager may transmit or receive broadcast messages. As previously described, this same authorization is required for a virtual bus and lazy susan. A device sending a message directly addressed to another device must be authorized to send to that particular DTE just as the receiving DTE must be authorized to receive from that source DTE.

Request messages are transmitted only to the FI Manager just as response messages are transmitted only from the FI Manager. Currently, any other message type not herein defined is invalid and would be recognized as an error by the FI Manager.

A device may wish not to communicate on the FI but to merely monitor traffic. Although this form of communication cannot be classified as a message type (such as direct address or virtual bus) because it is for monitoring only, it has been provided for in the request message format and is dotted in Figure 5-47 to indicate its possible presence.

5.3.3.3 FI error control. Controls are incorporated into the FI system design to: 1) Control the effects of data transmission and processing errors created within the FI; and 2) report them to the FI Manager to record for system error performance evaluation. Error control requirements imposed on the FI are separated into two types: Data errors and header errors. They will be discussed separately below.

5.3.3.3.1 Data error control. The FI is required to provide an undetected bit error rate (BER) better than $1x10^{-12}$ on all data transmitted over it, from LIU input to LIU output. The device header is not considered part of the data block. Direction was given to assume an inherent channel BER of $1x10^{-8}$ on the composite EI and LI transmission media. This appears to be a valid assumption since: 1) The fiber optic link should provide better than $1x10^{-10}$ BER with the margin on the receiver signal-to-noise ratio of about 10 dBm, and 2) the BER on the intrashelter (LI) flat ribbon cable should be better than 10^{-9}. The errors are to be considered statistically independant to simlify the analysis during this study. The burst nature of the EI and LI transmission media are obviously statistically dependent. The cryptographic equipment itself, if it is of the cipher-text autokey (CTAK) type, multiplies single bit errors into strings of 100 or more bit errors. However, long strings of errors are not the problem when row or column parity checks or hamming codes are employed. Burst errors of a period short with respect to the word length do present a problem with parity checks. Data transmission offered by the FI even in the presence of short burst errors will be of relatively high quality.

If an error is detected in the data, by the receiving LIU, the data is discarded and the LIU sends a data error message to the receiving DTE (assuming the header was received error free). Four functions are required in the FI to implement data error control:

a. Error detection coding in the transmitting LIU;
b. Error detection in the receiving LIU;
c. Data error message generation in the receiving LIU; and
d. Transfer of the error message to the receiving device.

Two methods of error detection were considered in Task III, and are included in this discussion. The first was parity checks on the data and the second method was a Hamming or other BCH-1 code. Although the BCH provides better error performance, and meets the 1x10-12 BER requirement in a short burst error environment of $1x10^{-8}$; both methods meet the requirement when assuming statistical independance and cryptographic extension of the errors. Since the implementation of the prity check method is much simpler to implement, it is the one chosen for the FI data error detection mechanism.

Parity check. As will be seen, two parity check bits on the whole block are adequate to meet the basic speicifcation for the data. If the parity checks must be performed as the data is strobed into the LIU on a word basis, it will be simpler to implement a parity check on each column of the entire data block. The column checks are simple parity checks on the vertical slices of the data block.

A single parity check detects error patterns with odd numbers of errors (1, 3, 5...). With low channel bit error rates, the only significant contributor to the undetected BER is the probability of 2 errors. The probability of occurance of error patterns of 4, 6, etc. are negligible with respect to the probability of 2 errors and therfore do not affect the undetected BER. Since only even errors are undetected, the undetected BER is equal to the probability of even errors occurring (P | even |), thus P | even | $\simeq$ P | 2 errors | .

To sufficienc accuracy, the probability of k errors in N bit data slices (words), assuming a channel BER P is:

$$P(k) = \binom{N}{k} p^k q^{(N-K)} = \frac{N!}{k!(N-k)!} p^k q^{(N-k)}$$

(k) is the number of ways k errors can occur in N bits. The probability of 2 errors (k=2) occurring in a given block is approximated to sufficient accuracy by the equation

$$P(2) \simeq N(N-1)\, P^2/2 \qquad (1)$$

which is the undetected block error rate. The undetected bit error rate is:

$$U = 2P(2)/N \qquad (2)$$

since P(2) is the probability of 2 undetected errors in N bits. Combining equations (1) and (2) yields:

$$U = (N-1)\, P^2 \qquad (3)$$

For the data, it has been specified that $U \leq 10^{-12}$ when $P = 10^{-8}$, and therefore, equation (3) can be solved for the maximum allowable value of N-1, which is the number of data bits in the block, the Nth bit being the parity bit:

$$N-1 = U/P^2 = 10^{-12}/10^{-16} = 10^4 \qquad (4)$$

---

1. $\frac{N!}{(N-K)!} = \prod_{i=0}^{k-1} (N-i)$, for k=2: $\frac{N!}{(N-2)!} = N(N-1)$

Also, for small p : $(1-p) \approx 1$

Four errors in a block yields a P^4 term in the expression for U, which yeilds a factor of 10^{-32}, which can be considered negligible.

The maximum data block of a packet will be 51_2 thirty-six-bit words, or 18, 432 bits. This is nearly as large as allowed for a single check by equation (4). Thus, at least two checks are required per maximum length data block. A vertical parity check on each column of the data block is equivalent to N = 513 bits, which yields an undetected BER on the data block of 5.12 X 10^{-14} which is greater than an order of magnitude better than required. Therefore, a word will be added to the packet trailer for vertical parity on each column.

5.3.3.3.2 Header error control. The FI is required to guarantee 5000 years mean time to undetected header error. The header is considered to comprise both the LI network header and the device header error. Direction was given to assume a message rate of 5000 messages per second, with the channel BER of 1×10^{-8} and the errors statistically independent. Only point-to-point transmission was considered in order to simplify the analysis.

If an error is detected in the header by the receiving LIU, it discards the packet and sends an error message to the FI Manager. Four functions are required in the FI to implement data error control:

a. Error detection coding in the transmitting LIU;
b. Error detection in the receiving LIU;
c. Header error message generation in the receiving LIU; and
d. Transfer of the error message to the FI Manager.

Both parity checks and BCH-1 methods of error detection were also studied for header error control. Both methods meet the 5000 years mean time to undetected header error. But, as in the case of data errors, the parity checks are much simpler to implement and, therefore, are chosen for the FI header error detection mechanism.

Parity check. As will be seen, both row and column parity checks are needed to meet the header error control specs. The required 5000 years mean time to an undetected header error, along with the following assumptions:

a. 5000 message headers/second,
b. 512 header bits (8 network header words & 8 device header words @ 36 bits/words) can be translated into an undetected BER in the header. The assumptions translate to:

   1. 7.884 X 10^{14} headers/5,000 years,
   2. 4.54 X 10^{17} header bits/5,000 years,

which in turn translates into a required header undetected BER of 2.2×10^{-18}.

Once the header undetected BER was determined it was used to determine the error detection method. Let the entire header consist of H=RS bits arranged in R blocks of S bits each. Each of the R blocks could be protected with its own parity bit. This would indicate a simple row or column check. A maximum value of R can be calculated that is required to satisfy the specification.

As for the data error detection, let P(2) be the probability of 2 errors in one block, and note that equation (1) of section 5.3.3.3.1 applies with R substituted for N-1. The probability of an undetected header error is then:

$$U = S\ P(2) = S\ (R+1)\ R\ P^2/2$$
$$= (H/R)\ (R+1)\ R\ P^2/2$$
$$= H\ (R+1)\ P^2/2$$

The specific requirements can be translated into single parity check equation parameters

$$U = 2.2 \times 10^{-18}$$
$$H = 512 \text{ bits}$$
$$P = 10^{-8}$$

and equation (5), when solved for the number of S 3-bit blocks (R) yeilds;

$$R \leq 8.6 \times 10^{-5}.$$

Since R is less than one, a single row or column parity check is not sufficient to meet the requirements.

Row and column parity checks were then analyzed. Consider a block of RC bits arranged in a rectangle as shown in Figure 5-48. The last row and the last column are made up of parity check bits on the column and rows. At least 4 errors are needed to escape detection, and these must be arranged at the corners of the rectangle as shown. Patterns of 6, 8, etc., errors can also be arranged to escape detection, however, the 10^{-48} factor produced in the value of U by 6 errors arranged in the header is negligible and can be ignored in the absence of burst errors.

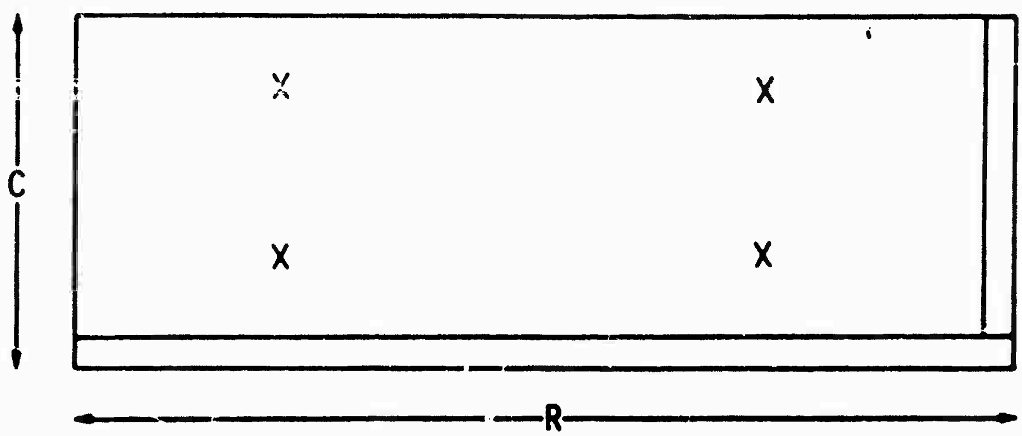


Figure 5-48. Pattern of four undetected errors.

The probability U of undetected block error is the product of the probability for each of these rectangular error patterns times the number of such patterns that can be formed in the R by C block:

$$U = R\ (R-1)\ C\ (C-1)\ P^4/4 \qquad (2)$$
$$= H^2\ P^4/4$$

where H = RC is the number of bits in the block. With H = 576 and $P = 10^{-8}$,

$$U = 8.3 \times 10^{-28}$$

which is significantly less than the required 2.2×10^{-16} undetected header BER.

Therefore, the horizontal and vertical parity checks will be used. The actual number of check bits required is R + C-1. For the format of the FI header, (R = 36, C = 16) there are 51 check bits required.

Consider now the effects of bursts errors on row and column checks. If the bursts are caused by crypto gear of the stream cipher type (also called cipher text autokey or CTAK), they consist of strings of 50 or more bits that are essentially random. In order to fool the column checks, a string of random bits must affect at least 2 rows. Therefore, it is checked by all the column checks and at least 2 row checks. Since the bits in the string are random, the probability of satisfying each check is 1/2, and if Q checks are involved, the probability that the string of errors will be undetected in 2^{-Q}. If the string laps over into more rows, its probability of passing the checks is halved for each row above 2.

The greatest chance for undetected errors comes when the error string ends on one of the last R-1 bits of the second row or starts on the first R-1 bits of the penultimate row. For this case, the probability of eluding detection is $2^{-(R+1)}$. The probability of having an error string fall in these two ranges is 2 (R-1) p, and the probability of undetected header error is:

$$U = 2\ (R+1)\ p\ (1 + 1/2 + 1/4 + \ldots)\ 2^{-(R+1)}$$
$$U = R\ P2^{-(R-1)}. \qquad (8)$$

With R = 36 and $p = 10^{-8}$, $U = 1.05 \times 10^{-17}$, and the specification is satisfied.

Against lower density bursts, the detection system is less effective. Consider an error source that puts out bursts of errors during which the error probability is p and with a duty cycle that makes the average error rate equal to 10^{-8}. The worst value of p will be one that gives an average of about 4 errors in a header. For a header with 576 bits (including checks) this is about 0.00069. The probability of getting a rectangular pattern of 4 errors during an error burst is:

$$U = R\ (R-1)\ C\ (C-1)\ p^4\ (1-p)^{574}/4. \quad (9)$$

This is like Equation 2 of Section 5.3.3.3.2.2, but because pH is no longer small, an additional term is needed. Evaluation U for P = 0.0069, R = 36, and C = 16 gives $U = 1.16 \times 10^{-8}$ during the bursts. This value is a little low because it does not include undetected patterns of more than 4 errors. The average value of U is found by multiplying by the duty cycle,

$10^{-8}/0.0069 = 1.45 \times 10^{-6}$:
$U = 1.68 \times 10^{-14}$.

This is much larger than the 2.2×10^{-18} undetected BER required to provide the 5000 year mean time to header error. $U = 1.68 \times 10^{-14}$ translates into one error in 6×10^{13} bits, which yields a mean time to header error of 661 years.

5.3.3.3.3 BCH codes. The error control system was analyzed using BCH error detection coding also. Even though the BCH method provides improved performance it was discarded in favor of the parity checking method, due to hardware implementation considerations. It is included here for comparison.

The simplest kind of BCH code is the well-known Hamming Code. The analysis that follows shows that a Hamming code will meet the requirements but a BCH code with greater minimum distance weight would be a little more effective.

A Hamming code with an additional overall parity check detects all patterns of 3 or fewer errors. It also detects all patterns of odd numbers of errors, and for even numbers of errors greater than 3 the probability of not detecting is close to $2^{-(J-1)}$ where J is the number of checks including the overall parity check. The maximum number of bits in the total block including checks is $2^{(J-1)}-1$. Therefore, 16 check bits is enough for the data block, and as few as 10 could be used for the header. From the standpoint of hardware economy, however, it makes sense to use the same code for both header and data.

When the errors are statistically independent (i.e., no bursts) and when the bit error rate p is small, the probability of undetected header error is:

$$U = (H+J)\ (H+J-1)\ (H+J-2)\ (H+J-3)\ p^4/(4! \times 2^{15}) \quad (1)$$

with $p = 10^{-8}$, J = 16, and H = 576, $U = 3.1 \times 10^{-27}$, a little better than with the row and column check using more than twice as many checks.

With error propagation from a stream cipher encryption system, the undetected error rate for the header is approximately given by:

$$U = (H + T - E)\ p/2^J. \quad (2)$$

T is the length of the random string that results from a single error at the decryptor input. The exact value of T for a given KG system is classified, but consideration of cryptographic security indicates that it should be at least 50. This value is used here to avoid classifying this document. E is an end effect allowance to take account of the fact that if the string overlaps only a few bits at the start of the header, the chance of getting the minimum 4 errors is small. Intuition suggests that 8 is about the right number, and since the effect is small, that value will be used and no detailed analysis will be made. With $H = 576$, $J = 16$, and $p - 10^{-8}$, $U = 9.43 \times 10^{-11}$, about 36 times as large as with the row and column code.

To get U down to 10^{-15} with cryptographic error propagagtion, J can be increased to 42.

Consider now the error detecting capability against burst errors with peak error rate about 0.0069 as was considered for the row and column checks. The probability of getting 4 or more errors in the block is 0.267, and the probability of failing to detect such error patterns is about 2^{-J}.
With $J = 42$

$U = 0.267 \times 2^{-42} = 6.1 \times 10^{-14}$, nearly 6 orders of magnitude better than the row and column check. If the bust duty cycle is 1.45×10^{-16}, as before, to make the average error rate $= 10^{-8}$, then

$U = 1.45 \times 10^{-16} \times 6.1 \times 10^{-14} = 8.8 \times 10^{-20}$ which meets the requirement of $U \leq 2.2 \times 10^{-18}$ for a 5,000 year mean time to undetected header error.

Although the above analysis is directed toward increasing the number of checks J by increasing the basic Hamming code block size and, of course, still using only as much of it as is needed, it would be a little more effective to go to a BCH code with higher minimum code word weight. The difference in hardware is probably small. The improvement in performance would be greatest with the non-bursty error patterns, and unfortunately it would not be appreciable against bursts of many errors.

5.4 Communication network implementation.

The communication system subnetwork includes that part of the TAF centers using telephones, teletype, low-speed serial data links, trunk groups, and transmission groups. It does not include the data transfer between ADP devices.

This section will identify major communication system users, their interconnectivity through the FI, and protocol required on the FI to handle communication messages. A concept for integrating some of the call processing functions required by telephone users is included in this section. Alternatives for a more extensive integration of call processing technical control and FI packet switching functions (developed in the Appendix) are evaluated in this section.

5.4.1 Communication interfaces by functional types. In Task II, a representative set of communication devices was identified with characteristics exercising the most important functions of the FI. This set was selected so the design of the FI adapters could be concentrated to a smaller number of functions. Otherwise, analysis of the FI interface could be too cumbersome. Table 2-8 lists those devices by functional types.

Each functional type was identified as an adapter type. These adapter types are shown in Figure 2-15. Other characteristcs of the signals are further identified in Table 2-2 through 2-6.

5.3.2 Network Interconnectivity: The interconnectivity of each of the functional types of communication devices is discussed in the following paragraphs.

Telephones - Telephones are interconnected either as dedicated circuits or on a switched basis. Dedicated circutis are routed directly from each end instrument to the technical control facility where each is patched through to its destination on a full-time basis. There is no supervisory signalling on dedicated circuits. Switched circuits are all connected from each end instrument to the circuit switch in the center. There is a supervisory signalling exchange between the telephones and the switch to set-up, maintain, and release each call. Loop-to-loop switched calls do not generally go through the technical control facility. Trunk calls, or those going between switches (at different centers), are routed through the technical control facility and over the transmission media. There is an additional switch-to-switch supervisory signalling exchange for trunk calls. The foregoing is true whether the end instrument is analog or digital, but the supervisory signalling exchange is quite different in each case. In both cases, the signalling is in-band.

Loop-loop calls originate and terminate off one switch within a center. In a loop-loop call the originating end instrument sets up the call with the switch by a supervisory signalling exchange. Refer to Figure 5-49. The switch sets up the destination circuit through the switching matrix with the destination device and the call takes place. The call is released with a similar exchange.

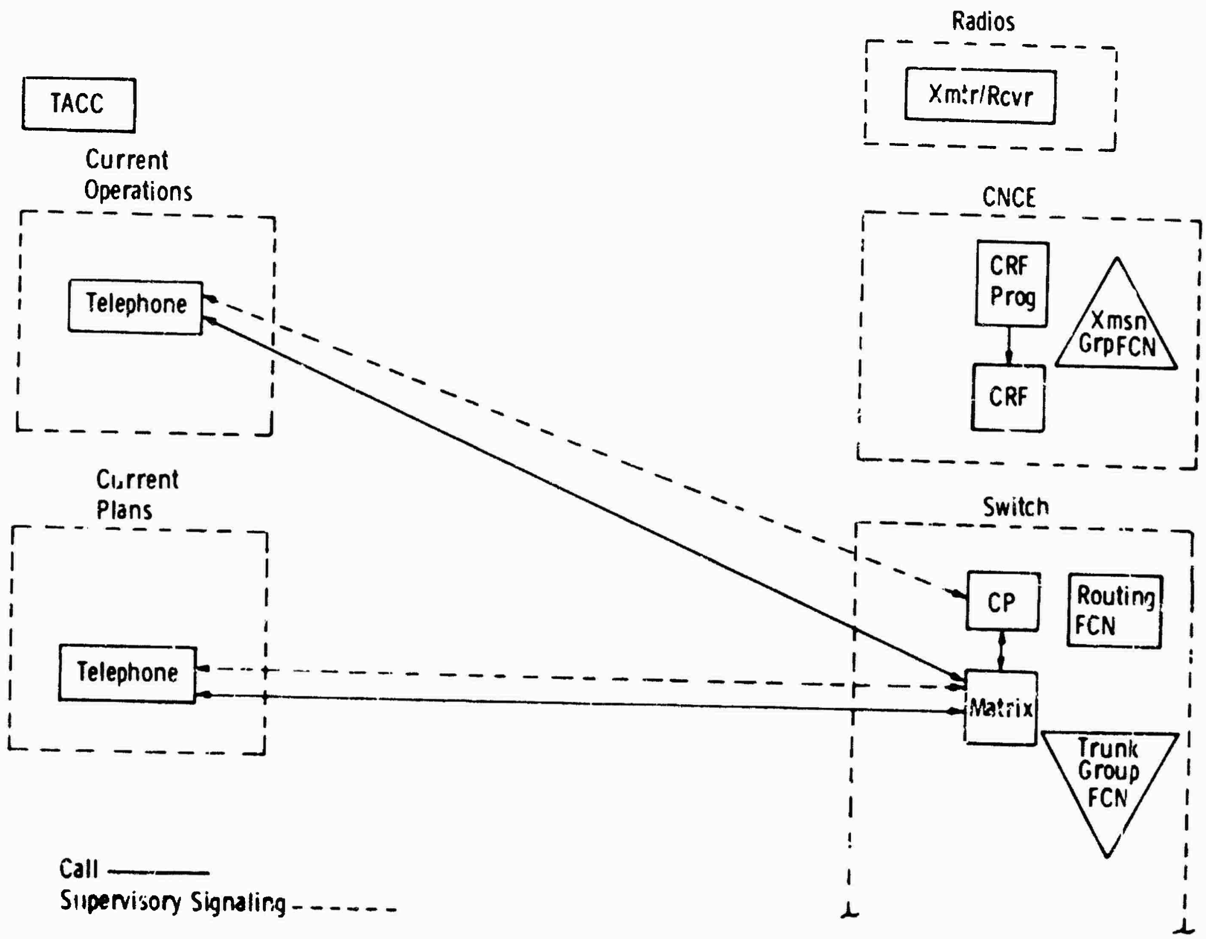


Figure 5-49. Loop-loop calls.

In a loop-trunk call, the initial set-up between the originating device and the switch is the same. But the switch must consult a routing function and communicate with the proper distant switch to complete the call. A trunk group is formed at the local switch and routed to the technical control facility where transmission groups are formed from trunk groups which are then routed over a radio or cable to the distant switch. Refer to Figure 5-50.

When the FI is used at a center, the interconnectivity is as shown in Figure 5-51 and 5-52 for loop and trunk calls. These figures show the access to the FI being made through the Local Intraconnect (LI) at each shelter. For clarity, communication adapters and components of the external intraconnect (EI) are omitted. Both signalling and call exchanges are carried as data within the body of the communications messages over the FI. Note that loop-loop calls traverse the FI twice from source to destination, and at least three times for trunk calls which go intercenter.

A more detailed breakdown of the interconnectivity is shown in Figure 5-53 for a digital telephone. The adapter (AD) used by each telephone is a low speed serial data (LSSD) adapter. The EICU is shown but no other detail of the EI.

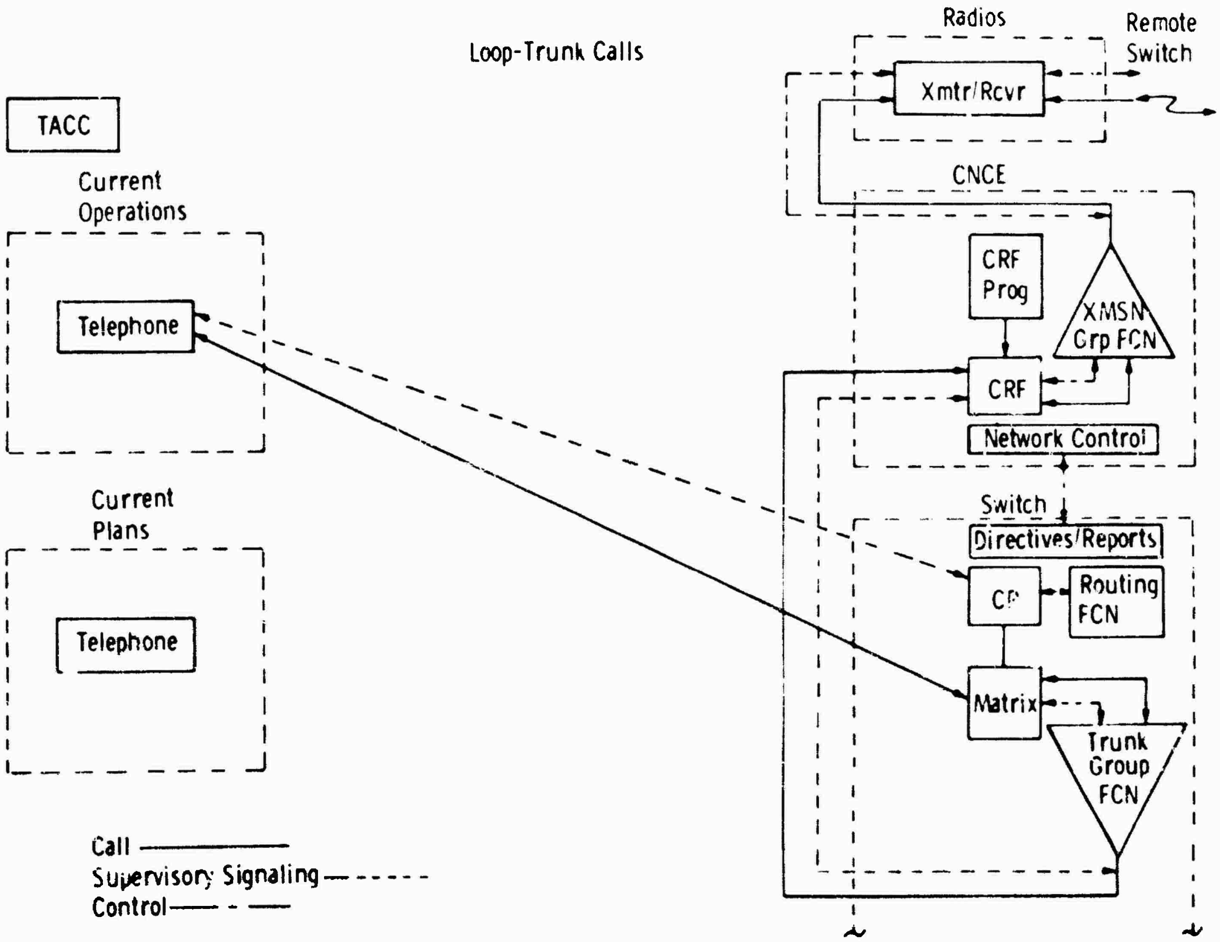


Figure 5-50. Call routing - typical AF center without flexible intraconnect.

Data Devices - A group of data devices representative of the TRI-TAC family in SCC-3 are shown interconnected through the FI in Figure 5-54.

TADIL A and B circuits are serial digital signals 150 b/s to 2250 b/s (Table 2-8) handled as quasi-analog signals in AV adapters. These are routed through the technical control facility as dedicated circuits to a radio. The analog telephone would generally be routed to the switch through the AV adapter. TADIL and telephone circuits would not necessarily use the same adapter and LIU as shown.

A teletype signal, in the CRC Ops central would use a data adapter (DA) to convert the TTY data to 16 kb/s or 32 kb/s. Encryption and supervisory signalling, required by the switch, can be provided by the DSVT (or DNVT) connected to the DA. Either way the converted teletype signal uses LSSD and is routed over the FI to either the switch or the technical control facility depending if the circuit is dedicated or switched.

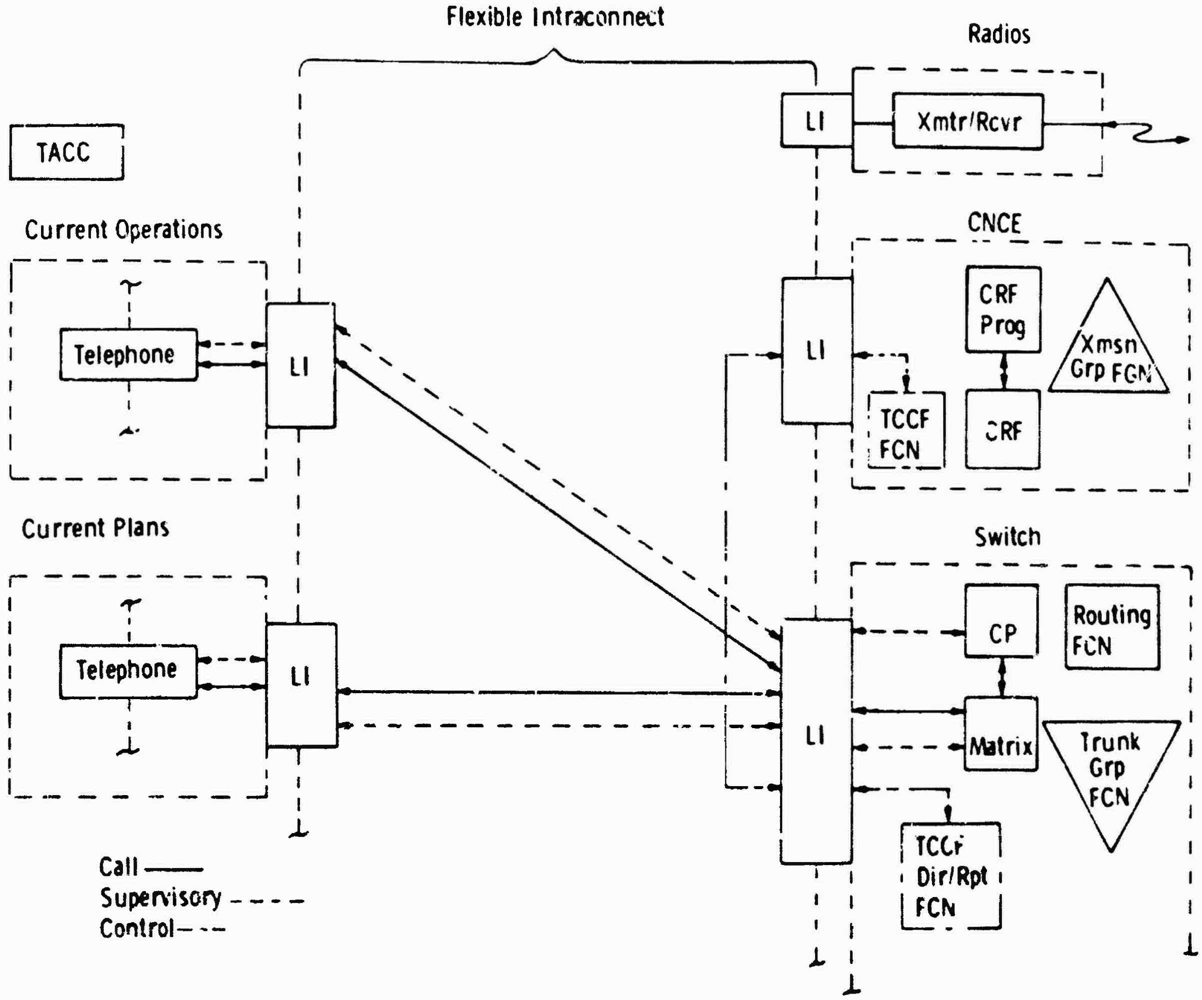


Figure 5-51. Call processor/FI integration concepts CF/FI separate noninterfacing intracenter (loop-loop) call.

Trunk groups are formed in the switch for intercenter transmissions. These are in the range of 144 kb/s to 4608 Kb/s (Table 2-8). Trunk groups use HSSD adapters and require one LIU for each adapter. The input to the HSSD is serial at the trunk group rate. The transfer from the HSSD to the LIU is across the standard interface which is 18-bit parallel, and the transfer from the LIU onto the LI is 36-bit parallel. A 4608 Mb/s trunk group would occupy approximately 10% of the total capacity of the LI at 10 Mw/s, and when message overhead is considered, it can be seen that the number of HSSD's (and LIUs) handled by one LICU is no more than seven when the HSSD's are operating at the highest rate trunk group. This limitation will be considered in implementing the CNCE and AN/TTC-39 with the FI.

Transmission groups are formed in the channel reassignment function (CRF) of the CNCE from trunk groups transmitted from the switch. Transmission groups are necessary because of different transmission paths used by the trunk groups. However, transmission groups in the CNCE are at the same family of rates as trunk groups and the comments made in the previous paragraph apply to transmission groups as well. Transmission groups are routed from the CNCE to the radio over the FI as shown.

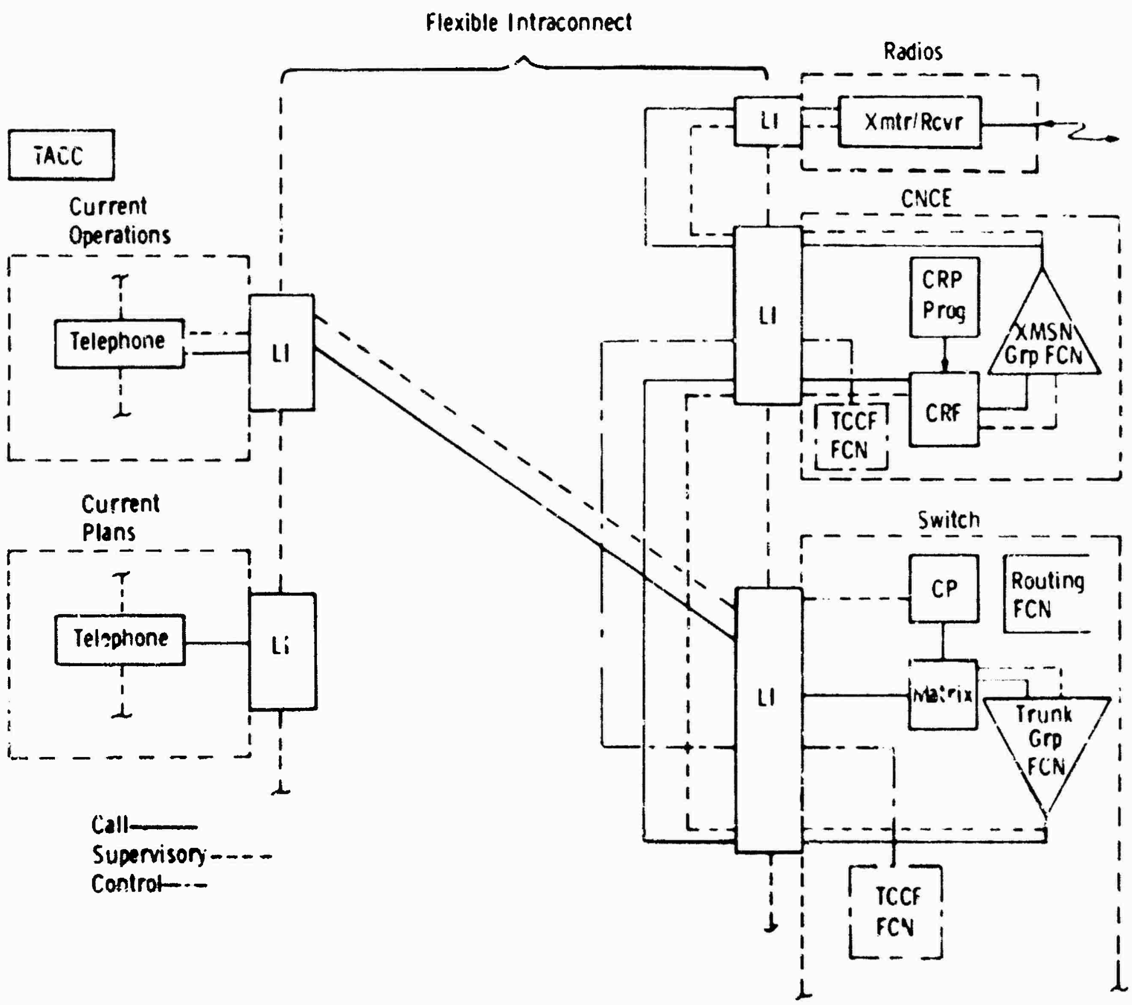


Figure 5-52. Call processor/FI integration concepts CP/FI separate, noninteracting intercenter (truck) calls.

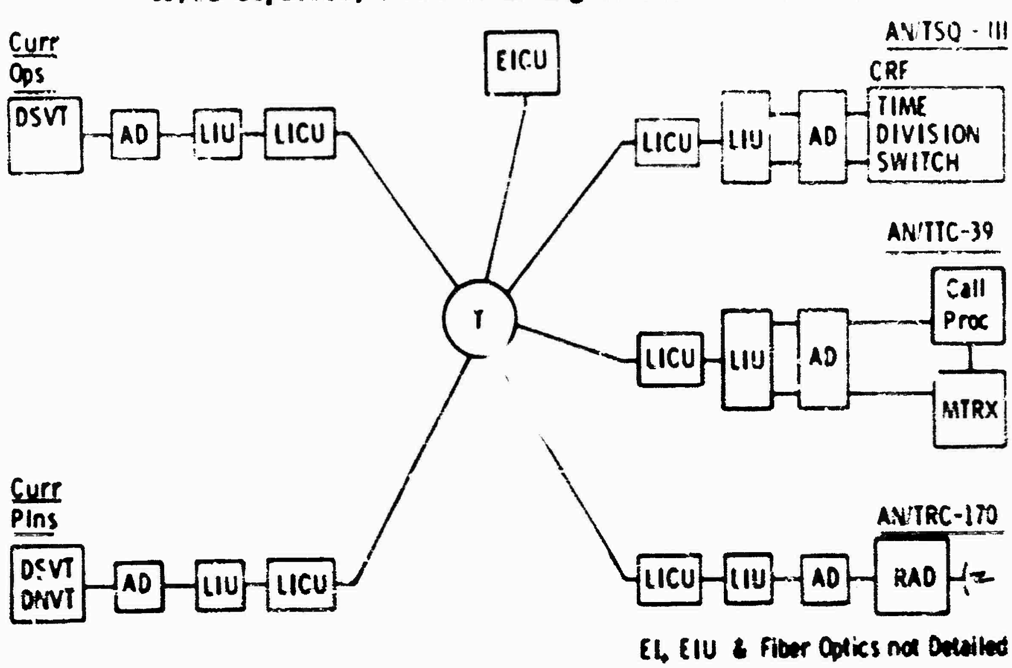


Figure 5-53. Digital telephone circuit - phase II bus, TACC center, SCC-364A.

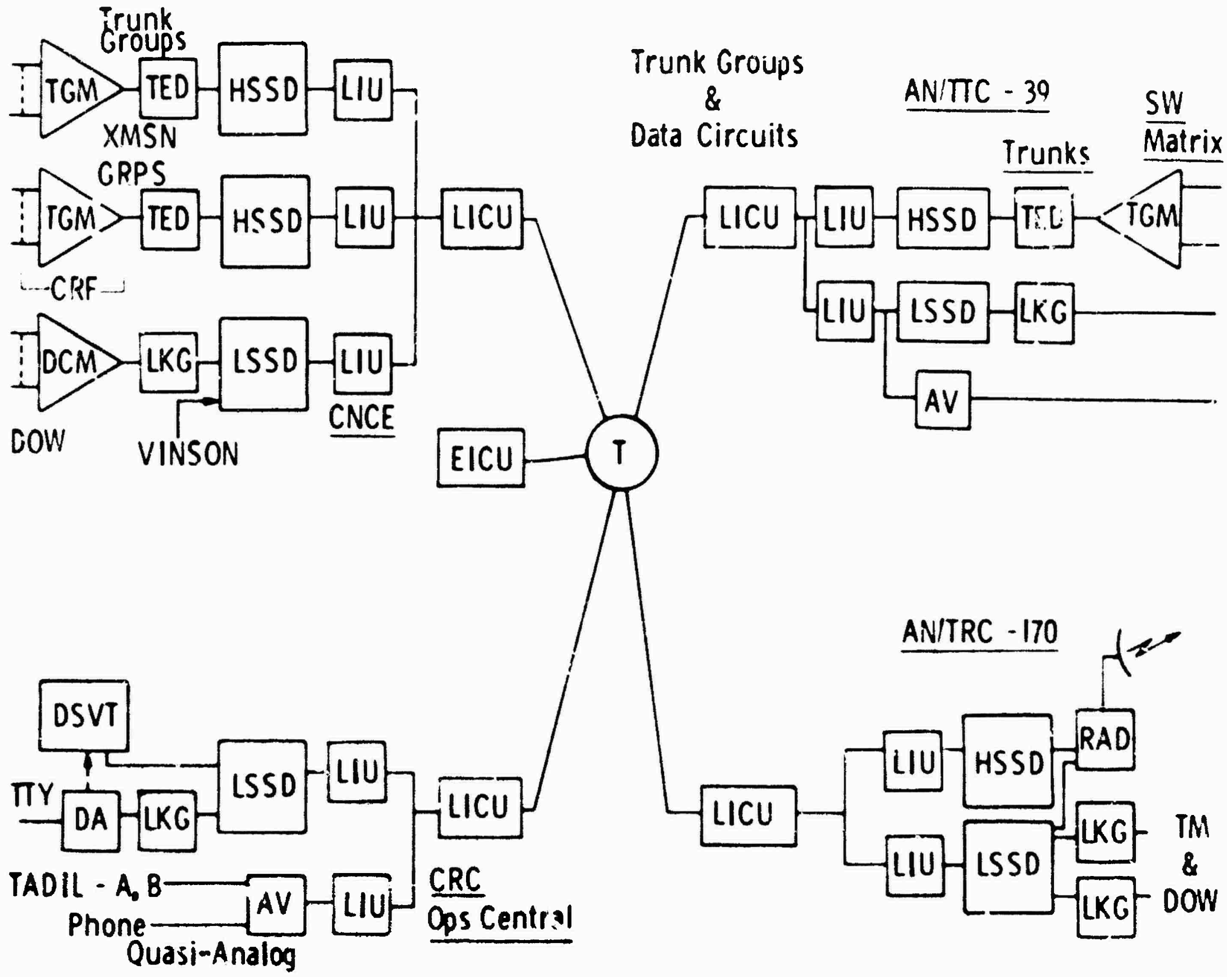


Figure 5-54. TACC - SCC - 3.

Another group of signals are the digital orderwires. They are telemetry, supervisory signalling, and digital voice with rates from 150 b/s to 4 kb/s, and 16 kb/s. These are defined in Table 2-8. The data signals can be combined in data channel multiplexers to 16 Kb/s or 32 Kb/s, or transmitted singly over the FI. In any case, the signals use LSSD adapters and are generally routed between CNCE, switch, and radios.

5.4.2 Communication subnetwork protocol. The communication subnetwork can be best analyzed by considering its two characteristic modes of transmission over the FI; point-to-point and intercom transmissions. The intercom mode is employed primarily for intrashelter telephones, or those within an operational complex such as the combined current ops and current plans facility of TACC of operations central of the CRC. These will be served by one LICU and LI. The point-to-point mode is used for connectivity, requiring transmissions over the External Intraconnect. The point-to-point mode services all intershelter traffic and will be primarily telephone traffic from center shelters to and from the circuit switch and technical control facility. The message structure, which is the same for both modes, will be described when the detailed operation of each will be made.

5.4.2.1 Communication message structure. Communication messages are formed in communication selected adapter units (SAU). Each SAU puts the response from the 10 devices it serves into the body of the message and attaches the device (DTE) header and trailer. The device header and trailer are 5.3.3.2, Figure 5-44 of this report.

The SAU forms a header and trailer in addition to the device header (Figure 5-55. A communication header of up to 20 18-bit words is formulated, a two-word section for the response from each device. The header contains the destination address (the LIU and the adapter port) and any classmarks, precedences, etc., associated with the calling device.

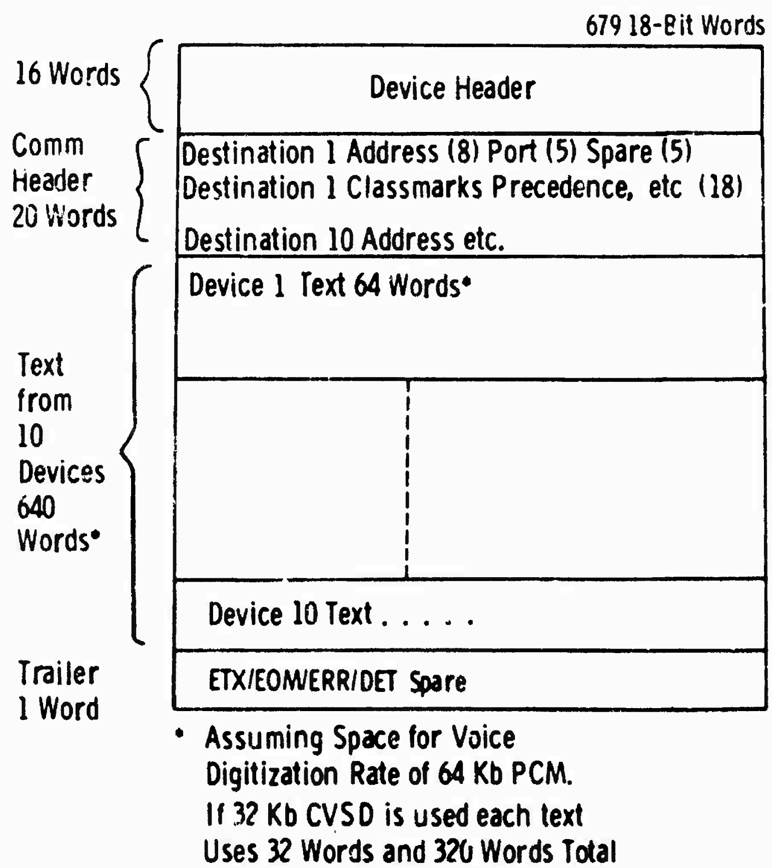


Figure 5-55. Low-speed communication adapter response format.

The body of the communication message contains the response from each active device. Each device may use up to 64 18-bit words and each message may contain up to 640 18-bit words of text. An inactive device will not have its header appended and will not occupy space in the text. The length of the message will, therefore, depend upon the number of active users on the SAU. The size of the block of device text was set at 64 words to account for accumulating 18ms of 64 kb/s (PCM) voice, or, 1152 data bits. If the voice digitization rate of 32 kb/s (CVSD) is used, the text block size would be reduced to 32 words, or 576 bits of data, and the total text from 10 devices

would be 320 words instead of 640. (It has been determined that 18ms is an optimum sample interval for transferring voice on the FI, considering message occupancy, efficiency, hardware complexity, and transmissions delay time over the FI. Each communication DTE is, therefore, sampled on 18ms interval). A one-word trailer is attached to the message to denote end of textual data.

In general, all active devices attached to an SAU will not always be included in each message. If a device has a destintion on the EI, it will not be included in a message destined for the LI only. Similarly, messages going over the EI will not contain local II traffic. The SAU will distinguish between user destinations of its devices and formulate separate messages for each.

5.4.2.2 Intershelter communication. When a communication device communicates with a device in another part of the TAC center, or in another center, it will do so over the EI as a point-to-point communication. It may operate as either a switched circuit or a dedicated circuit in the TAC environment. As noted before, switched circuits will all be routed from the devices directly to the circuit switch (or store and forward switch in the case of data), and dedicated circuits will be routed directly to the technical control facility. In general, then, devices in any shelter will have no more than two external destinations and any SAU can service all intershelter traffic from its devices by formulating only two messages, one to the switch and one to the technical control facility. Any messages from an SAU will have only one destination shelter, or LICU. The switch and technical control facility are exceptions. Messages from SAUs in these shelters may have more than two destinations and require the formulation of more than two messages during an 18ms interval to service all its devices.

The point-to-point protocol for the transfer of communication messages is shown in Figure 5-56. Delays in FI buffers are shown in the figure. There is a fixed 18ms delay in the adapter to account for storage of a block of data. There are polling delays in acquiring access to the LI and EI which may be up to 18 ms. There are other shorter load-dependent delays experienced on the downlink between LICU and LIU, and LIU and SAU. This protocol is the same as for any other point-to-point message on the FI described in Section 5.3.3.2. It should be noted that all device data from one originating SAU will be delivered to one destination LICU and from there, delivered to all LIUs on that LI. Each LIU with a destination address in the message will accept the message and pass it on to its SAU where the proper point to which the destination device(s) are connected is decoded.

5.4.2.3 Adjacent, or intrashelter communication (intercom): An intercom network can be set up on the FI whereby any communcation users on one LI can communicate without going through the switch or technical control facility. The intercom capability is valuable in larger centers such as TACC and CRC where several modules can be collocated and a large number of devices are served by one LICU (LI). Where the intercom capability can be effectively utilized a considerable traffic load can be removed from the circuit switch.

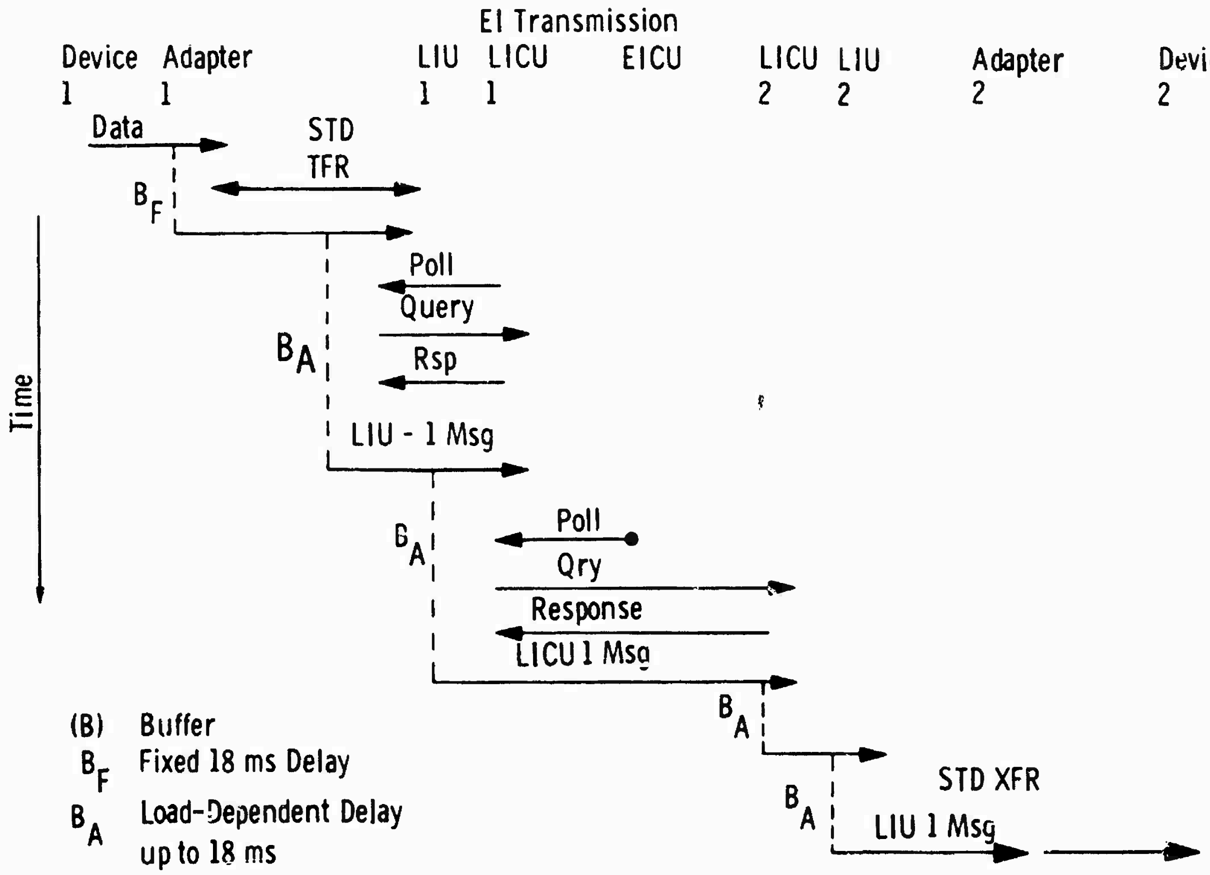


Figure 5-56. Communication protocol - point-to-point data transfer between two communication devices.

Intercom communications are feasible because each LI is a common bus wherein each transmission from one party is broadcast to all LIUs on the LI. The intercom network uses the virtual bus mode of communication. A virtual bus is set up between all communication users on an LI. The set-up and operation of a virtual bus is described in Section 5.2.2. The protocol for this mode of operation between two devices is shown in Figure 5-57. When the LICU polls an LIU, the SAU message is transferred to all users (LIUs) on the virtual bus, i.e., those with communication SAUs. These users pass the message onto their SAU's where device port addresses are decoded.

Call processing required for intercom communication is done in the SAUs. One device may call another by inserting its address into the DTE header. This can be done from the instrument or by an attachment such as a push button. Permanently dedicated circuits may be made by programming destination address into the SAU. Party lines and conferencing may be accomplished by similar manipulation of device addresses in the SAU. Access can be made to classmarks and precedence assignments by either FI controller or by the user. The intercom capability can provide the user with many of the simpler call processing functions now provided by the switch. The requirements for capability will be developed in a later phase of the program.

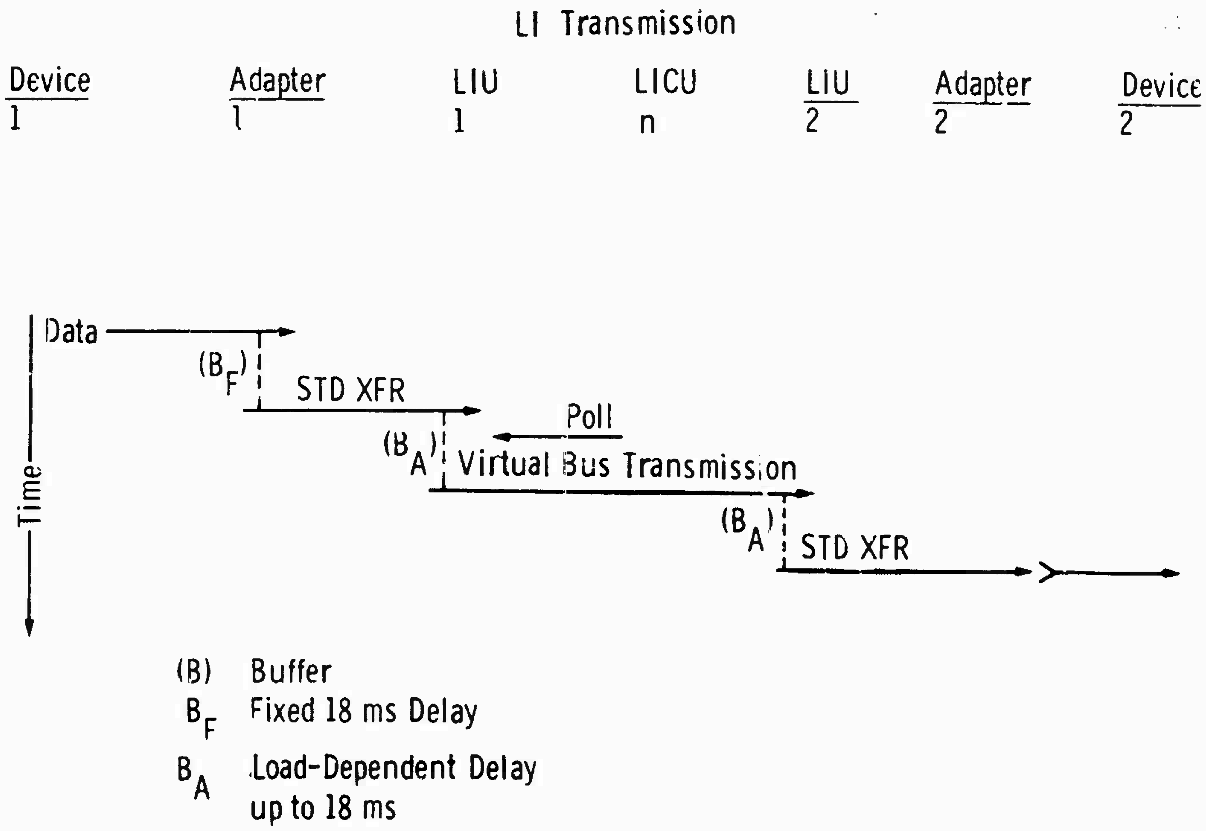


Figure 5-57. Communication protocol - intercom between two communication devices.

5.4.3 Integration of packet switching properties of the FI with other COM switching functions. In Task I, SCC-4B was developed that, in part, assumed the integration of all switching functions of the circuit switch and technical control facility with the packet switching functions of the FI. In Task III, this concept was investigated further to determine more of the system requirements and to assess what degree of integration in curcuit switch and tech control functions was fesible.

Two implementations were considered. These are in addition to the intercom concept described in 5.3.3, which is not a bonafide integration of functions because, even though it will offload the switch to some degree, it is not intended to replace any existing switching functions. One concept, referred to as Call Processing on the FI, assumed the transfer of all loop call processing functions of the circuit switch and its associated interchange with the technical control facility, to the FI. The other concept, referred to as Circuit Translation, assumes that all call processing and switching functions normally residing in the circuit switch and technical control facility would remain there and an address translation function would be added to interface with the FI to provide a circuit bypass of the switch and technical control facility when their call processing and supervisory functions were complete. Both concepts considerably reduce traffic over the FI. Both concepts have been developed in some detail and included in Appendix A.

5.4.3.1 Call processing on the FI. The concept of call processing on the FI was the one most nearly like that intended in the integration concept proposed in SCC-4B. It was the basis for the traffic load projected for SCC-4B. The change in the concept from that time has been to exclude the trunking and transmission group functions from the integration process. Therefore, the reduction in traffic loading is due only to loop calls and not to trunk calls as SCC-4B assumed. The reason for this is basic to the concept.

In reviewing the functions that now, or normally, reside in the circuit switch and technical control facility, it was determined that the functions associated with trunking, e.g., primary and alternation routing, interswitch supervisory signalling, area and zone controls, etc., were too complex and specialized to be made part of the FI and should be done by the switch and technical control facility no matter what concept was selected. Consequently, the call processing functions for loop-loop calls were the only ones considered for removal from the switch and inclusion on the FI.

5.4.3.2 Circuit translation. The motivation for conceiving the circuit translation concept was to simplify the FI call processing function from Section 5.4.4.1. It would allow all the specialized functions performed by the switch and technical control facility to remain there unchanged and still provide a means by which the functions performed by the FI would not be duplicated by these units. These functions are: all curcuit switching, including trunk group switching and formulation in the switch; all transmission group switching and formulation in the technical control facility channel reassignment function; and all modem functions in both facilities. Since the circuit translation function affects trunk groups and transmission groups as well as loops, the traffic reduction predicted in SCC-4B can be fully realized.

The circuit translation concept has the greatest impact on the configuration of related TAC communication equipment. The reduction in capability and complexity of the circuit switch and technical control facility has significant impact on these facilities. Since it is not considered to be in the best interest of the FI to produce a design having large impacts on other TAC equipment, it may be desirable to propose implementation of this concept in two phases. The first phase would not change either the switch or technical control facility. Address translation could be done at the interface to both facilities using signals now existing in the equipment. The address translator could be appended to the FI. The address translation would reduce the traffic load by eliminating redundant paths from the device through the switch and technical control facility but would not reduce switching crosspoints, multiplexers, and modems in the facilities. The second phase would affect the complete integration of the functions with its corresponding reduction of circuit switch and technical control equipment.

5.4.3.3 Comparative evaluation. A comparison was made of the two integration concepts and compared to the non-integrated system as it would be without either one. The most apparent advantages and disadvantages of the concepts are summarized in Table 5-20.

TABLE 5-20. INTEGRATED FI CONCEPTS

FI/Call Processing/TCCF		
Concept	**Advantages**	**Disadvantages**
1. Nonintegrated Call processor and TCCF functions are separate from FI. Non-interacting	1. Least FI complexity 2. Switch and CNCE require no modification	1. Maximum BW reqts (both loop-loop and trunk calls require separate paths from device-SW-CNCE-radio, i.e., requires multiple paths on FI).
2. Call Processing on FI: CP loop-loop functions and TCCF functions integrated on FI. Trunk functions are separate.	1. Efficiency of address functions and related operations (they are designed into FI) 2. Decreases complexity of switch by removing all loop-loop CP and TCCF functions. 3. Medium BW reqts. (no multiple paths on FI for either loop-loop calls).	1. Adds complexity to FI. (All loop-loop CP functions from switch and their associated TCCF functions are included on it). 2. Trunk calls require multiple paths on FI between SW, CNCE, Radio
3. Circuit Translation: CP and TCCF functions remain separate from FI. Interacting address translation incorporated.	1. Minimum BW reqts. (no multiple paths on FI for either loop-loop calls or trunk calls). 2. Simplified FI (no CP or TCCF functions) 3. Simplifies switch and CNCE by eliminating necessity for signal paths through them	1. Complicates SW and CNCE by adding address translator. 2. Multiple paths are still required for supervisory signalling paths (but not for calls)

The non-integrated concept requires considerably more bandwidth than the others, but is otherwise the simplest to implement. It makes maximum use of existing systems, but in no way takes advantage of the potential of the FI for using distributed switching and multiplexing. As a result, this system allows considerable redundancy of switching and transmission functions between the FI, circuit switch, and technical control facility.

In FI call processing, the addition of the call processor to the FI greatly increases FI complexity. This addition does not seem to justify the gain in efficiency of the FI addressing functions and other operations (compared to circuit translation) or the decrease in bandwidth requirements due to a reduced number of times a call traverses the FI. The latter is largely due to the fact that only loop-loop calls are effected in this concept.

The circuit translation concept has the greatest use of distributed switching and multiplexing capabilities offered by the introduction of FI packet switching into the system. It offers advantage in reduction of FI bandwidth and eliminates redundancy of switching, multiplexing, and transmission functions.

5.4.3.4 **Recommendations.** The first implementation of the FI should incorporate only that call processing required to implement the intercom capability on the LI as described in Paragraph 5.4.2.3. This is, in effect, the recommended concept for near-term implementation and provides a minimum impact on existing TAC communication equipment and has the desirable effect of somewhat off-loading traffic from the circuit switch.

The next phase of FI implementation should be the incorporation of circuit translation into the switch and technical control facility to the extent that all interacting signals in these facilities can be brought to the FI and the address translation performed external to the circuit switch and technical control facility. This will provide considerable off-loading of traffic from these functions while leaving the capability in existing equipment for back-up during transition phases.

The last phase is the full-scale incorporation of circuit (address) translation into the circuit switch and technical control facility and the elimination of all redundant matrix switching, multiplexing, and modem functions from these facilities.

5.4.4 Wideband analog transmission. In Task I, the need was identified to transmit wideband analog signals over the FI. These were radar signals at the CRC/CRP, ASRT, FACP, and TWAC, and TV video signals from surveillance aircraft to the AFCH, and for navigational alignment purposes at the ASRT. The bandwidth of each of these signals is listed in Table 5-21.

Wideband Analog signals will be transmitted over the FI in analog form over circuits seperate from digital transmissions. Separate fiber or fibers will be used for WB analog transmissions over the EI. When a number of signals use the same link, such as the radar signals from the TPS-43 to the CRC OPS central, an FDM composite will be formed and the signal transmitted over one fiber of the EI. In other cases, such as the single TV video link at the AFCH, the baseband signal will be transmitted over one fiber of the EI.

The WB analog signal, whether multiplexed (FDM) or transmitted singly, will be routed through the EI transponder on a separate circuit from the digital EI. The WB analog signal will not enter the polling scheme or any other control the EI uses for digital signals. In other words, the WB analog signals are transmitted over the FI in a subnetwork independent from the digital FI system. It may be necessary to route the same WB analog signal to more than one destination, in which case isolation and WB drivers will be required at the transponder. (This need for multiple destination of the same WB signal has not yet been identified in this study). Implementation of some WB signals are shown in Section 7.0.

TABLE 5-21. WIDEBAND ANALOG, RADAR AND TV SIGNALS

CENTER	LINK	SIGNAL	BW(MHz)	CKTS
ASRT	TPB-1/TACAN	AZ & Control	3	4
	TPB-1/RADAR	Digital-Pulse	15	15
	TPB-1/RADAR	Video	10	1
	TPB-1/TV	Video & Sync	6	1
		TOTAL	34	
FACP	TPS-43/TSQ-61	Digital Control & Height	27.8	15
	TPS-43/TSQ-61	Radar	28.0	8
		TOTAL	55.8	
TWAC	WX RADAR/TMQ-28	Digital	1	1
	WX RADAR/TMQ-28	Video	6	1
	WX RADAR/TMQ-28	Azimuth	1	1
		TOTAL	8	
AFCH	TV RCVR/OPS CNTRL	Video	3.5	1
CRC/CRP	TPS-43/OPS CNTRL	Pre-Trigger	1.2	1
		IFF/SIF Composite	5.0	1
		MTI Gated Video	4.0	1
		Search Video	4.0	1
		Synthetic Video	0.6	1
		ACP	0.6	1
		North Mark	0.6	1
		Height Bits (9)	10.8	9
		TOTAL	27.8	

6.0 DEVELOPMENT OF THE INTERFACE STANDARD

6.1 Objective.

The objective of this analysis was to develop a standard set of interface characteristics to be adopted for the interface between the Flexible Intraconnect and all ADP and communication devices accessing the intraconnect. These characteristics were documented in a preliminary interface standard to provide guidance in the selection of I/O characteristics for future TAF C^3 device developments.

6.2 Constraints and assumptions.

It was agreed between the customer and Martin Marietta that the standard should define a rigid interface. This implies that there should be no capability to modify the interface with either hardware or software. Imposing a rigid standard on the diverse equipments to be connected to the FI will reduce the possibility of error. The standard must spell out in detail exactly what is required for a successful interface. Any additional software or hardware required to accommodate an interface with a device not conforming to the standard should exist in an adapter module. If more than one standard is chosen, there should be a uniquely designed Local Intraconnect Unit (LIU) for each standard.

The possibility of connecting a CCD memory system to the FI in the future was submitted by the customer. This proposed memory system could be similar to the Burroughs Scientific Processor (BSP) file memory which can transmit at a sustainable rate of over 10 Mw/s. It was agreed between the customer and Martin Marietta that the initial design of the LIU need only accommodate up to 5 Mw/s, with provisions for a later change to a maximum rate of 10 Mw/s being effected by only a modification to line drivers/receivers.

6.3 Analysis approach.

It was agreed between the customer and Martin Marietta that logical boundaries for development of the standard were to be modeled after the I/O structure from one of four candidates: The IBM 360/370, PDP-11, Intel 8080/85, or a Martin Marietta designated CPU. After preliminary study, it was decided there was no need for a fourth candidate CPU since the three designated CPUs represent the most dominant and widely used CPUs in the large computer, minicomputer, and microprocessor industries. As such, these CPUs are industry-wide supported with hardware, software, and peripherals.

The interface standard has evolved from an analysis of the requirements and comparison of the features of the candidate I/O structures to those established in Section 2.3.3.1 (ADP Equipment Interface Analysis).

6.4 Results.

The Task II Final Report discussed the candidate I/O structures, the selection of the 8085, and several adapters to the interface. The results are summarized herein to show how the interface standard evolved.

6.4.1 Candidate I/O structures. Because of its complex timing and handshake routine that is unlike most other CPUs, the IBM 360/370 I/O structure was discarded as a candidate. The PDP-11 was strongly considered because of its simple and straightforward UNIBUS configuration. However, actual implementation of an interface based on any I/O structure would probably be accomplished with a microprocessor-based design because of its flexibility, smallness of size, and small power requirements. Thus, it was decided to place emphasis on a standard that more readily accommodates small processor capabilities.

6.4.2 Microprocessor Selection: A comprehensive investigation into the Intel family of microprocessors led to the selection of the Intel 8085 as the basis for the FI interface standard. The 8080/85 features justifying this selection include:

a. 8080/85 involvement in more microcomputer applications than all other microprocessors combined;

b. 7 years of software development; and

c. Availability of a high-level language (PL/M) designed for system and applications programming. Other software support includes:
   - Resident assembler,
   - Cross assembler and simulator for Fortran IV,
   - Debug, diagnostic and edit programs.

d. Hardware support includes:
   - Prototyping system,
   - In-system emulator.

e. Second sources include AMD, NEC, National Semiconductor, and T.I.

f. RCA to develop 8085 C/MOS SOS version by April, 1979.

The essential considerations* resulting in this choice can be summarized as:

a. Foremost hardware and software support for the Intel 8080/85 microprocessors; and

b. The prominent position of the Intel 8080/85 in the microprocessor industry.

6.4.3 DMA operation. The 10 Mw/s requirement guides the operation of the interface towards a direct memory access (DMA) type of transfer rather than one which is CPU-controlled. A DMA operation as it applies to the LIU is shown in Figure 6-1.

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* Since this study was done, Intel has announced the 8088, its newest microprocessor having twice the performance of the 8085 and operating with a 16-bit interior structure. An interesting aspect is that the 8088 has an 8-bit external bus structure identical to that of the 8085, thus strengthening the justification of this selection.

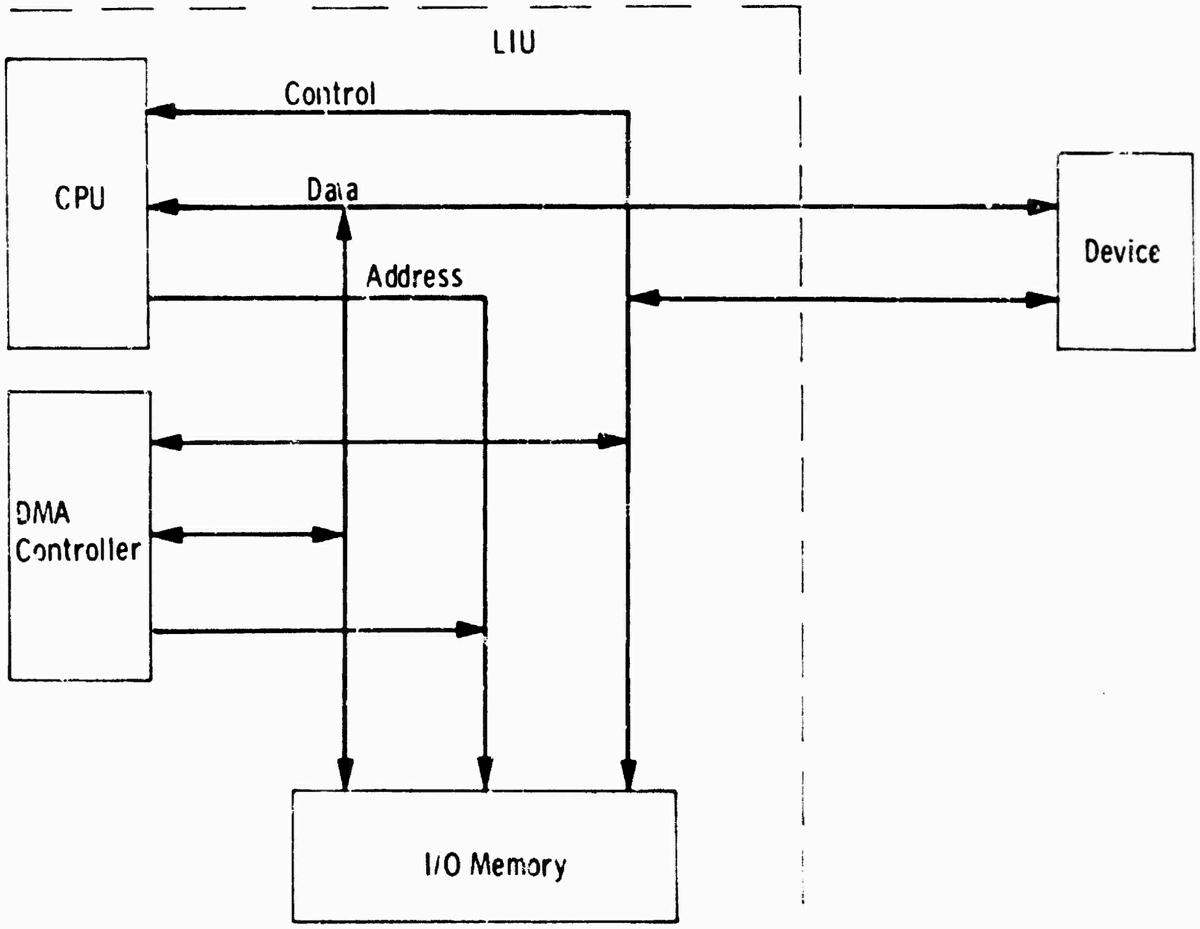

Figure 6-1. DMA operation.

Since very little processing capability is required in the way of control when moving blocks of data between the I/O memory and the external device, and also since the CPU is too slow to accommodate transfer rates of 10 Mw/s, a DMA controller will be used to control the block transfer. One of the functions of the DMA controller is maintaining a pointer that indicates where the next word of data for transfer should go in I/O memory, or where it is located. This pointer will be incremented after each word transfer. The starting address, that is, the address of the first data word, is normally provided by the CPU.

Another function of the DMA controller is maintaining a count of the words transferred, and continually comparing this count with the desired block length. When the predefined count is reached, the DMA operation is halted and control of the buses returns to the CPU. The CPU normally provides the word count that defines block length. The CPU also sets the mode control, such as direction of data flow.

Once the CPU has supplied the starting address, word count, and mode control, it relinquishes bus control to the DMA controller. All data transfers are then carried out under control of the DMA controller. At the end of the block, control is returned to the CPU.

Using the Intel 8085 family of components, the fastest DMA transfer would be 750k bytes/s. A DMA controller using high-speed logic would thus have to be specially designed and built in order to meet the 10 Mw/s criteria.

Figure 6-2 shows the DMA configuration as applied to the LIU. The only modification is the addition of the Input Data Request (IDR) and the Output Data Request (ODR) control lines. IDR will interrupt the LIU when the DTE wishes to initiate a data transfer and will remain set during the entire block transfer. At the end of the block, IDR will be cleared. Thus, in addition to acting as an interrupt to the LIU, the IDR also provides a verification of the word count by communicating the data block size to the DMA controller.

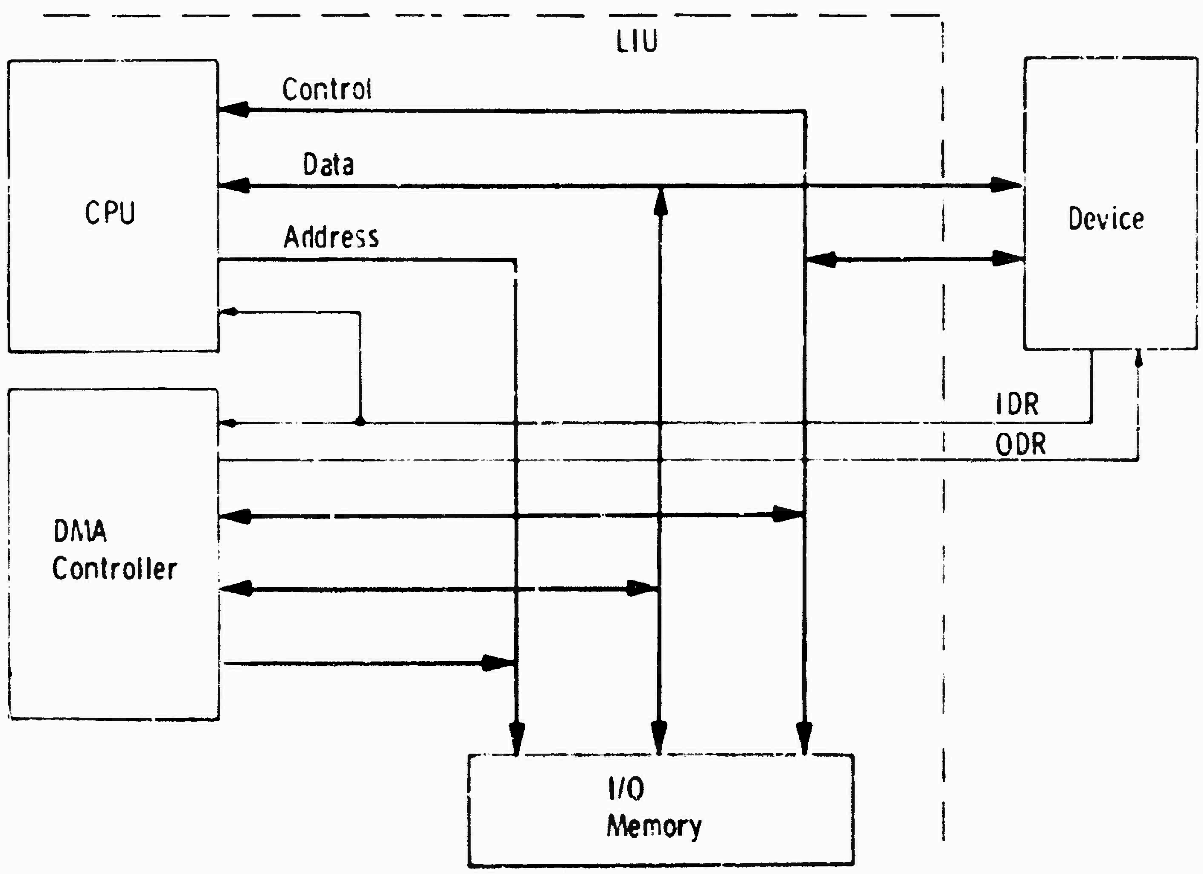

Figure 6-2. DMA operation with LIU.

ODR performs an identical function for the LIU-to-device transfer as the IDR does for the opposite direction.

6.4.4 Interface resolution. In Task II, Martin Marietta advocated an interface standard based on the Intel 8085 I/O Bus Structure. RADC has considered this proposed standard as well as others in generating the current interface standard.

A software header has been added to data being transferred between the LIU and DTE. This header contains information on the system mode, message type, FI virtual addresses, message length, message number, date and time, and parity error detection. Although the header is generated by the DTE, it is not transparent to the FI and can be modified by the LIU.

Another modification concerns the handshaking between the LIU and DTE. In addition to ODR and IDR, the control signals recommended by Martin Marietta were the READY, WR, and RD signals as defined by the Intel 8085. These signals exhibit the master-slave relationship in the timing and handshaking routine as observed in the majority of the CPUs analyzed in Task II. The current standard replaces these three control signals with the two signals (LRE/LRF and DRE/DRF) described in the Interface Standard. This creates a symmetrical interface, rather than a master-slave configuration. This type of interface allows the direction of the control lines during the transfer of data in one direction (LIU-to-DTE or DTE-to-LIU) to be reversed during the transfer of data in the other direction (DTE-to-LIU or LIU-to-DTE).

6.4.5 Implementation of DMA at interface. A possible implementation of the current interface standard is shown in Figure 6-3. This example shows static random access memories (RAM) being used as data buffers. The 2114 RAM is a popular component in the industry, being sourced by several semiconductor companies. It is organized as 1024 words by 4 bits, thus five would be required for each unit (LIU or SAU) to accommodate the present requirement of a 1024 X 18-bit buffer. It can be seen that only a minimal amount of logic is required to adapt the 8085 bus signals to the interface standard and to operate in a DMA mode as shown.

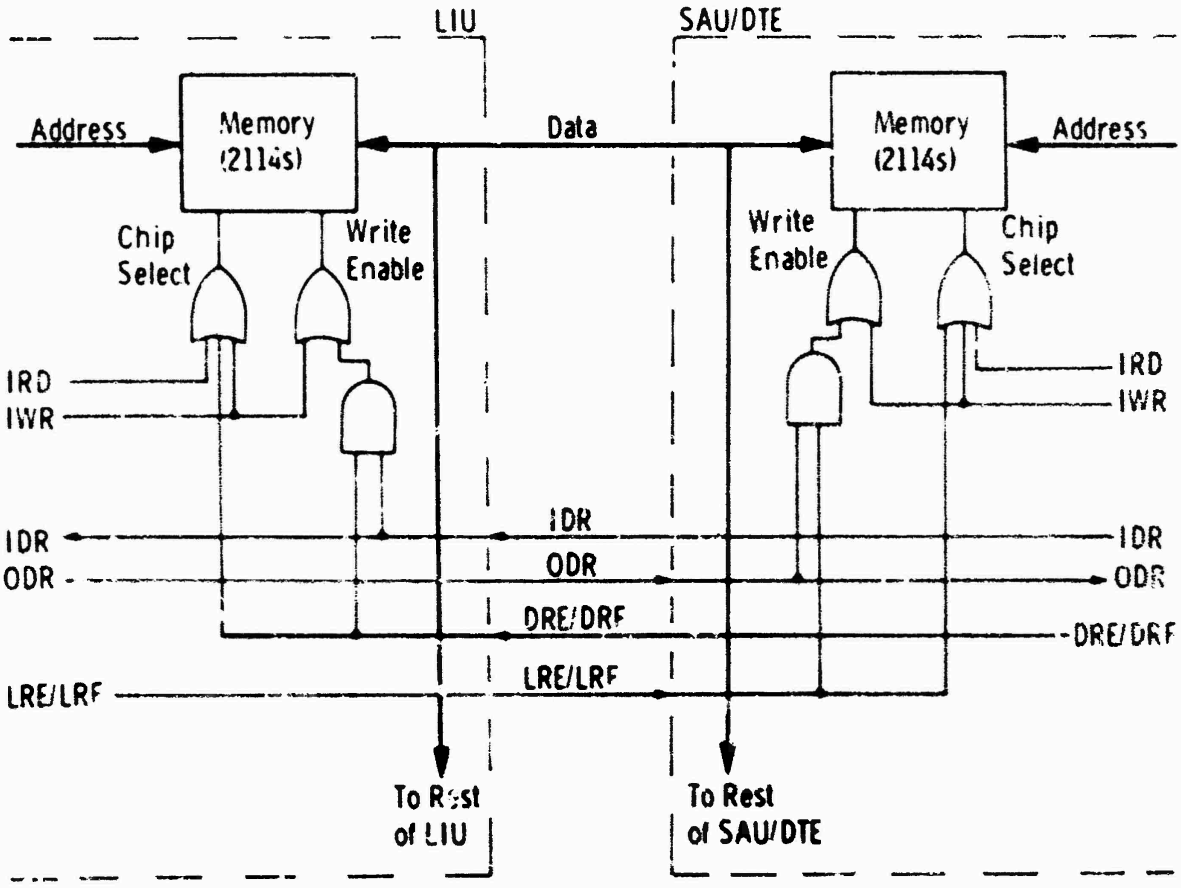

Figure 6-3. Implementation of DMA at interface.

The Internal Read (IRD) and Internal Write (IWR) are required to allow the LIU and DTE to access their respective memories for their internal use. These signals as well as the interface control signals can be generated as shown in Figure 6-4.

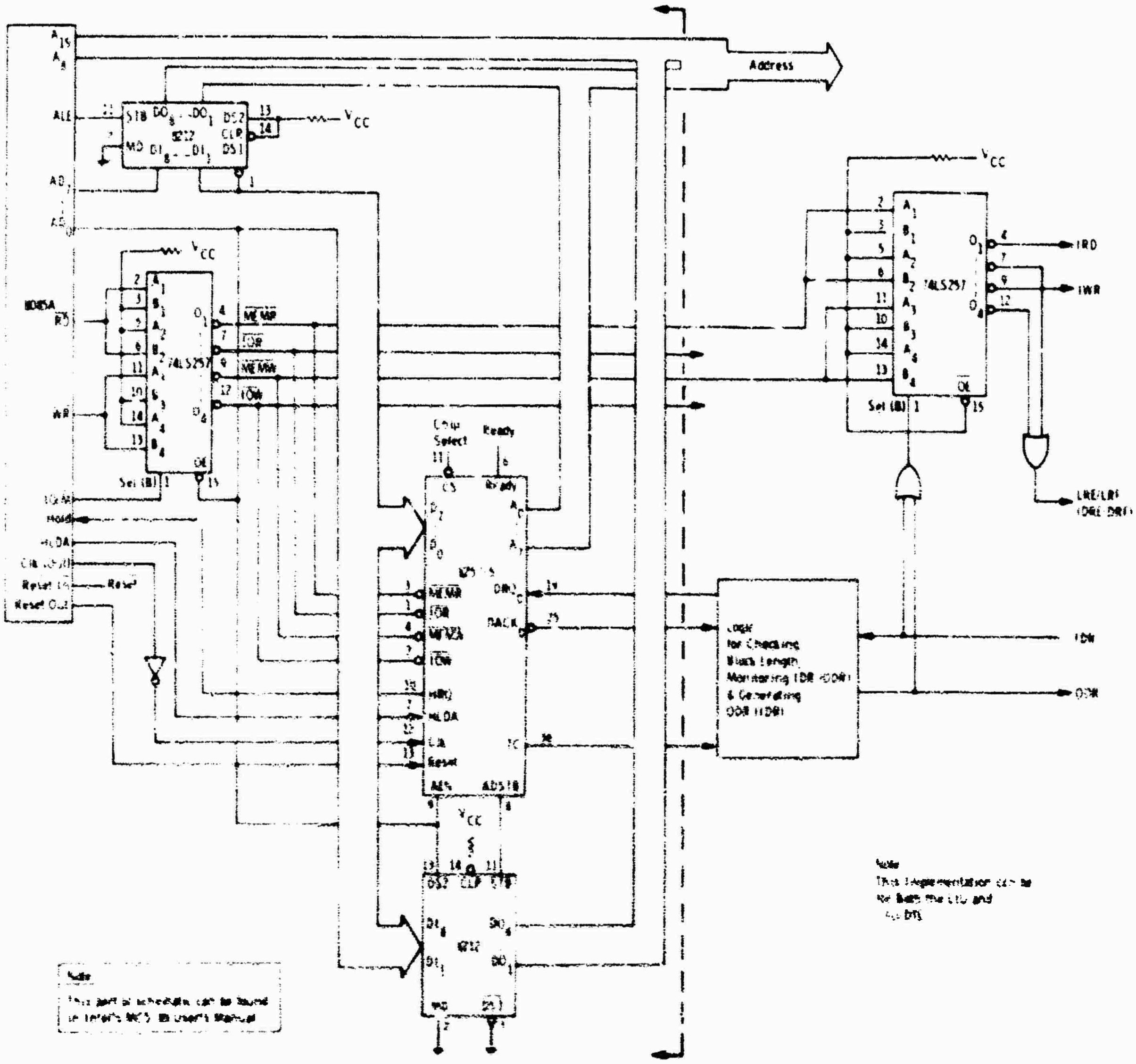

Figure 6-4. Implementation of control lines for interface DMA.

Timing diagrams for transfer of data in either direction are illustrated in Figures 6-5 and -6.

6.4.6 Selected Adapter Unit (SAU). To connect with the FI, the I/O structure of a DTE must conform to the requirements defined in the Interface Standard. All ADP equipment identified in the Task II cannot currently accommodate the interface as defined. Selected adapter units (SAU) will be needed to connect these equipment to the FI.

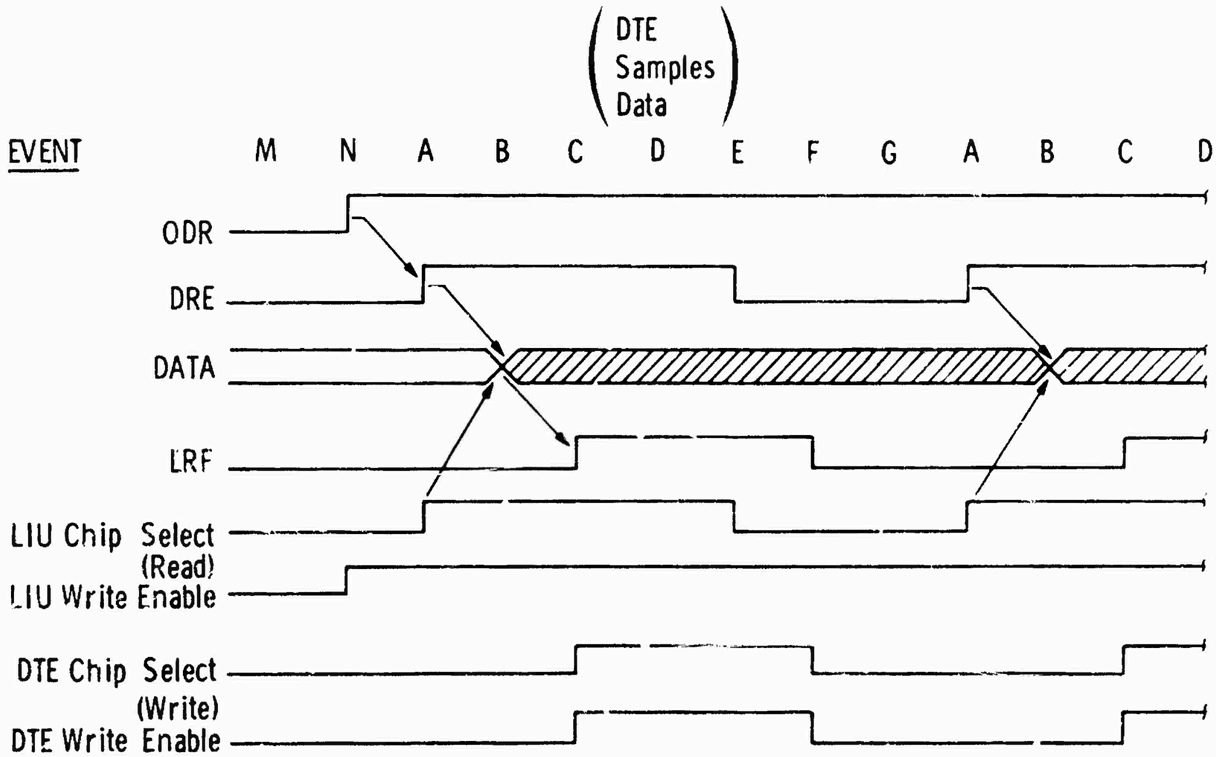

Figure 6-5. LIU-DTE DMA timing.

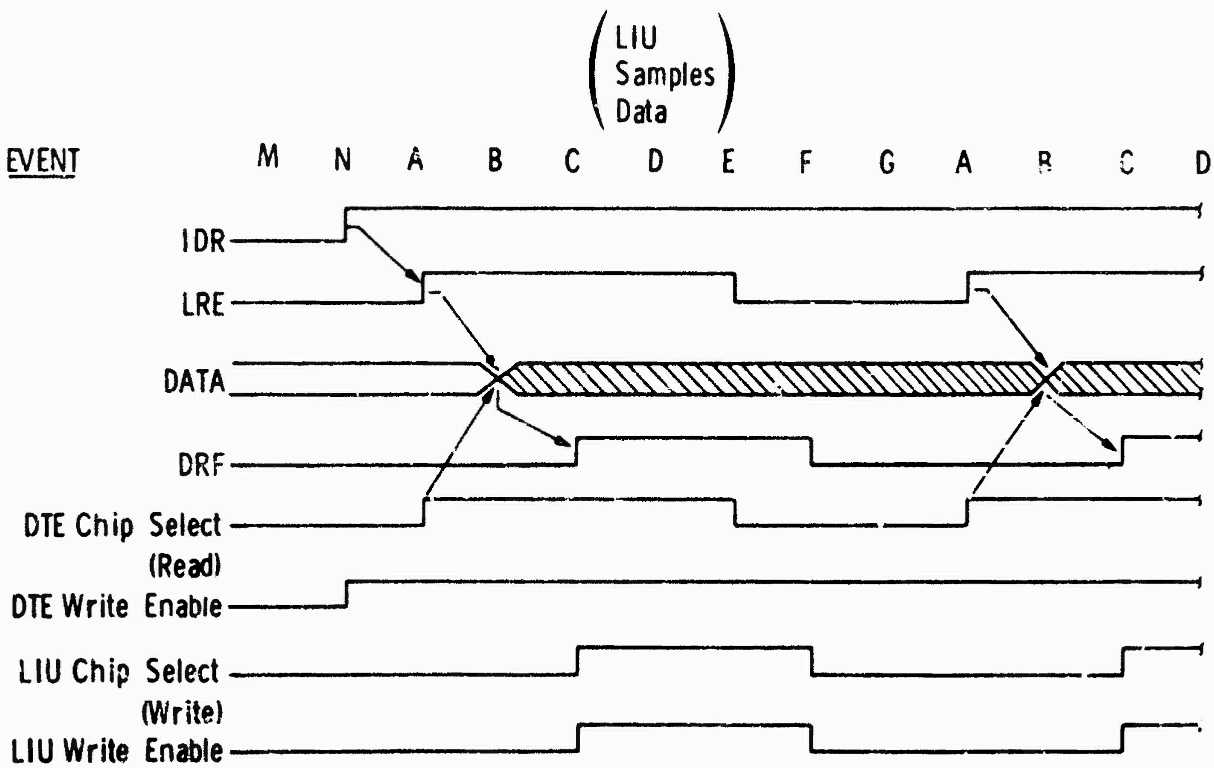

Figure 6-6. DTE-LIU DMA timing.

By implementing the interface between the LIU and DTE with an Intel 8C85-based SAU, an entire family of components is immediately available for use, including:

Programmable communication interface;
Programmable peripheral interface;
Programmable floppy-disk controller;
SDLC protocol controller;
Programmable CRT controller;
IEEE standard 488 controller; and
UPI-41 family of microcomputers.

Figure 6-7 shows an SAU based on the 8085. In addition to supplying the device header, the 8085 initially programs the peripheral component to run in the desired mode of operation. The data would normally be transferred to and from the memory via the peripheral component from and to the DTE. The 8085, DMA controller, memory, and logic could remain standard for most adapters. There should only be a change of peripheral component and program memory to interface with many devices. Most of the SAUs could be grouped according to common functions. For example, identical SAUs can be used for all MIL-STD-1397 Type B interfaces, for all PDP-11 peripherals, or for all RS-232-C interfaces.

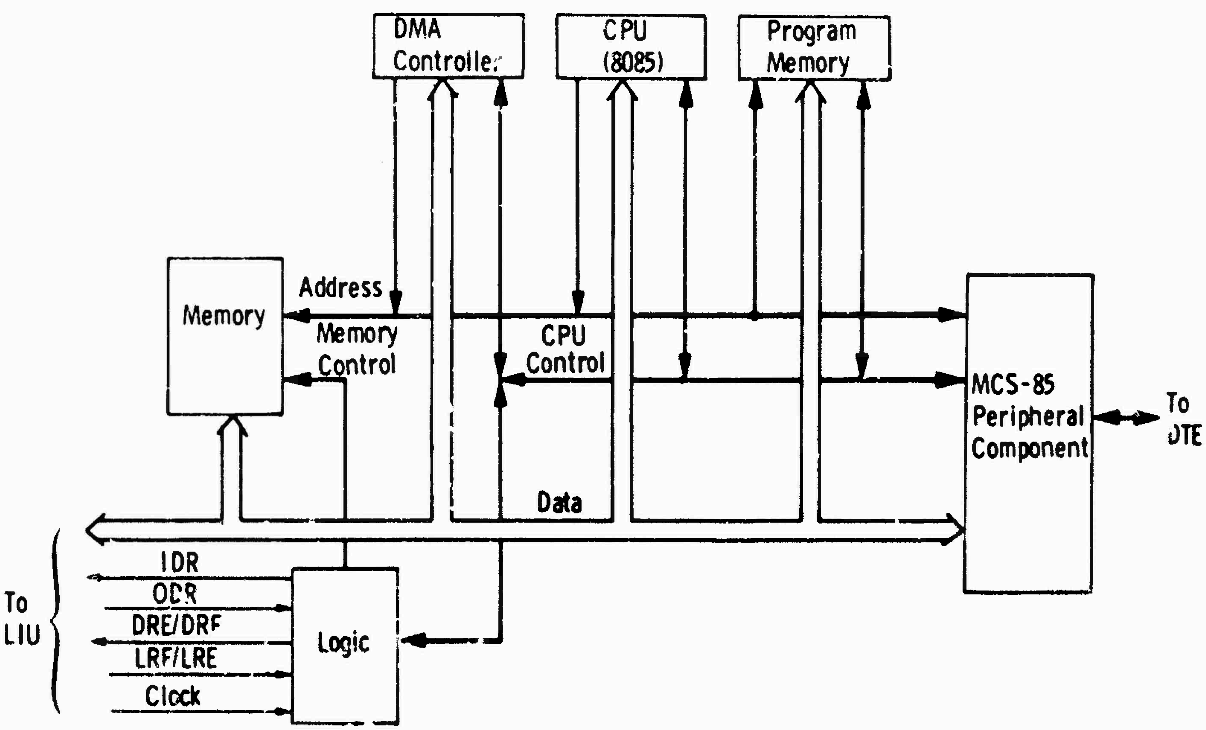

Figure 6-7. Intel 8085 supported SAU.

6.4.7 **SAU examples. Examples of adapting some of the I/O structures prevalent in the industry to the current interface standard are discussed below.**

6.4.7.1 Serial communication. The Programmable Communication Interface (Figure 6-8) is a version of the industry standard Universal Synchronous/Asynchronous Receiver/Transmitter (USART). It is programmed by the 8085 to operate using virtually any serial data transmission technique presently in use. The USART converts data from serial to parallel form to the data memory, and vice-versa to the DTE. The serial mode depicted in this case is the RS-232-C standard. The SAU is shown adding/extracting one data bit in order to convert the 8-bit parallel data from and to the 8251 to the 9-bit parallel data form required by the interface standard.

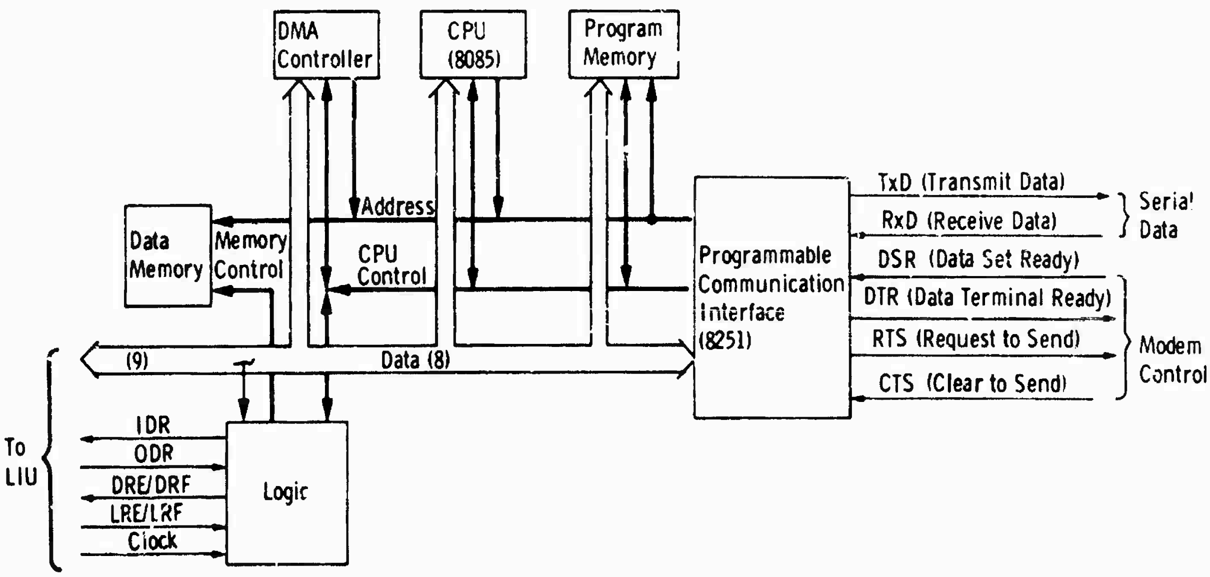

Figure 6-8. Serial communication/FI interface.

6.4.7.2 IBM 360/370 channel. The Universal Peripheral Interface (UPI) shown in Figure 6-9 contains a microcomputer with program memory, data memory, 8-bit CPU, I/O ports, timer/counter, and clock in a 40-pin package. Interface registers are included to enable it to function as a peripheral controller for the 8080 or 8085. The function of the 8085 would be to supply necessary block headers to the LIU and to initialize the UPIs into the proper mode of operation. This would be accomplished first for one UPI, then the other, via the Mux/Demux. The UPI would then communicate directly with the data memory during the data transfer, with the 8085 becoming involved again only at the end of the block transfer (to conclude the operation). Although the IBM 370 voltage levels are near that of TTL, voltage level shifters may be desired to guarantee the specified voltages.* Latches may be required to transform the control pulses from the IBM channel to binary levels for mapping of the control signals into data. Refer to Figures 6-10 and -11 for IBM 360/370 timing.**

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*IBM Field Engineering Self-Study Course: Introduction to System/360 I/O Operations, 3rd Edition, IBM, Poughkeepsie, N.Y., 1968.

**IBM System/360 and System/370 I/O Interface Channel, 4th Edition, IBM, Poughkeepsie, N.Y., January, 1976.

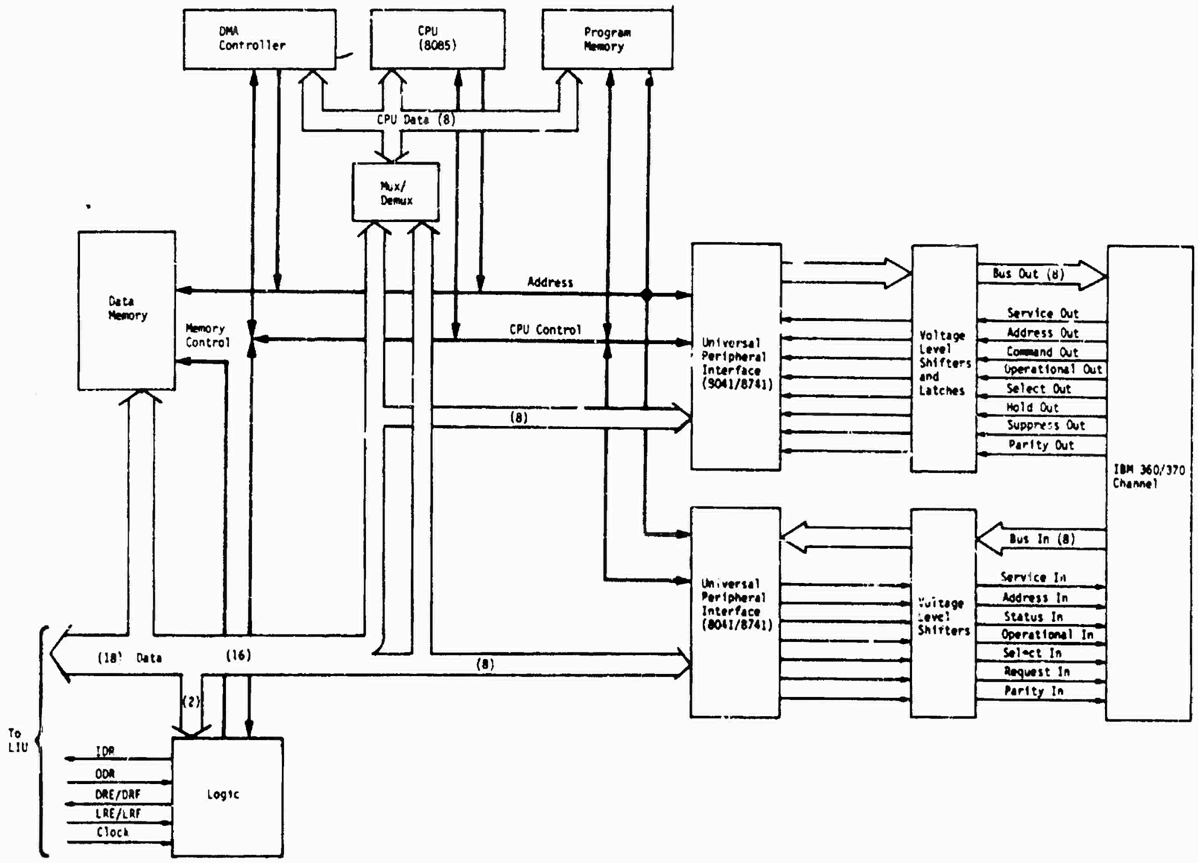


Figure 6-9. IBM 360/370 channel interface.

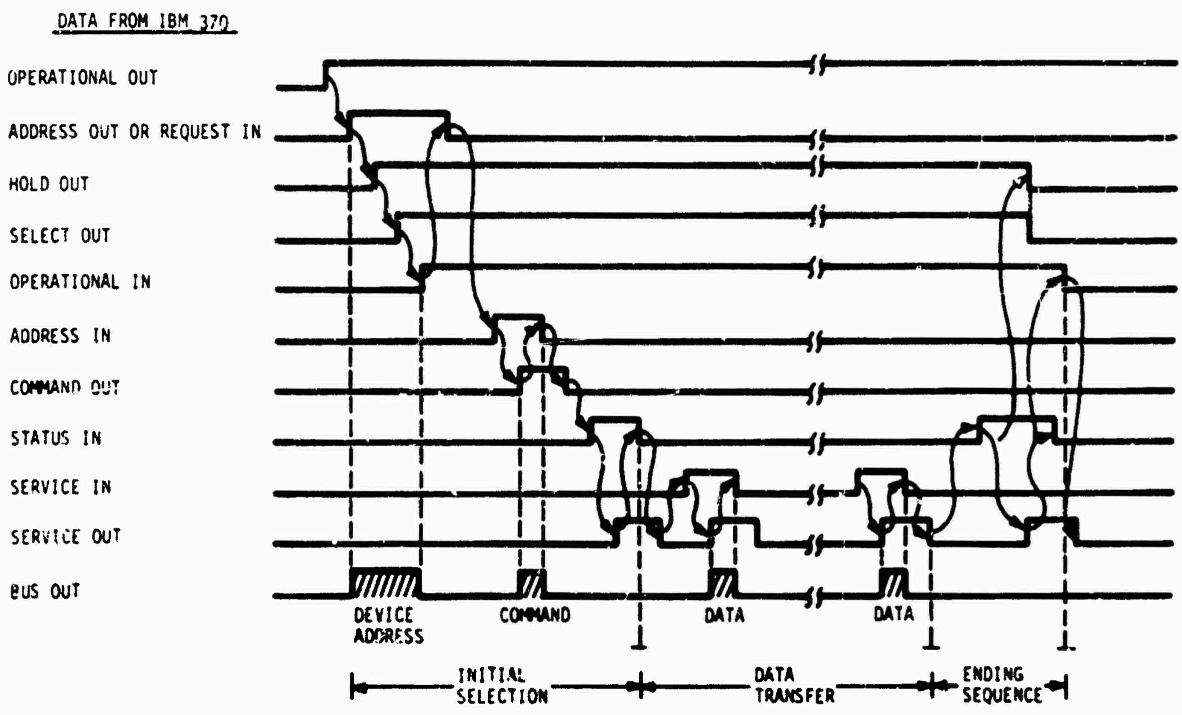


Figure 6-10. IBM 370 channel timing.

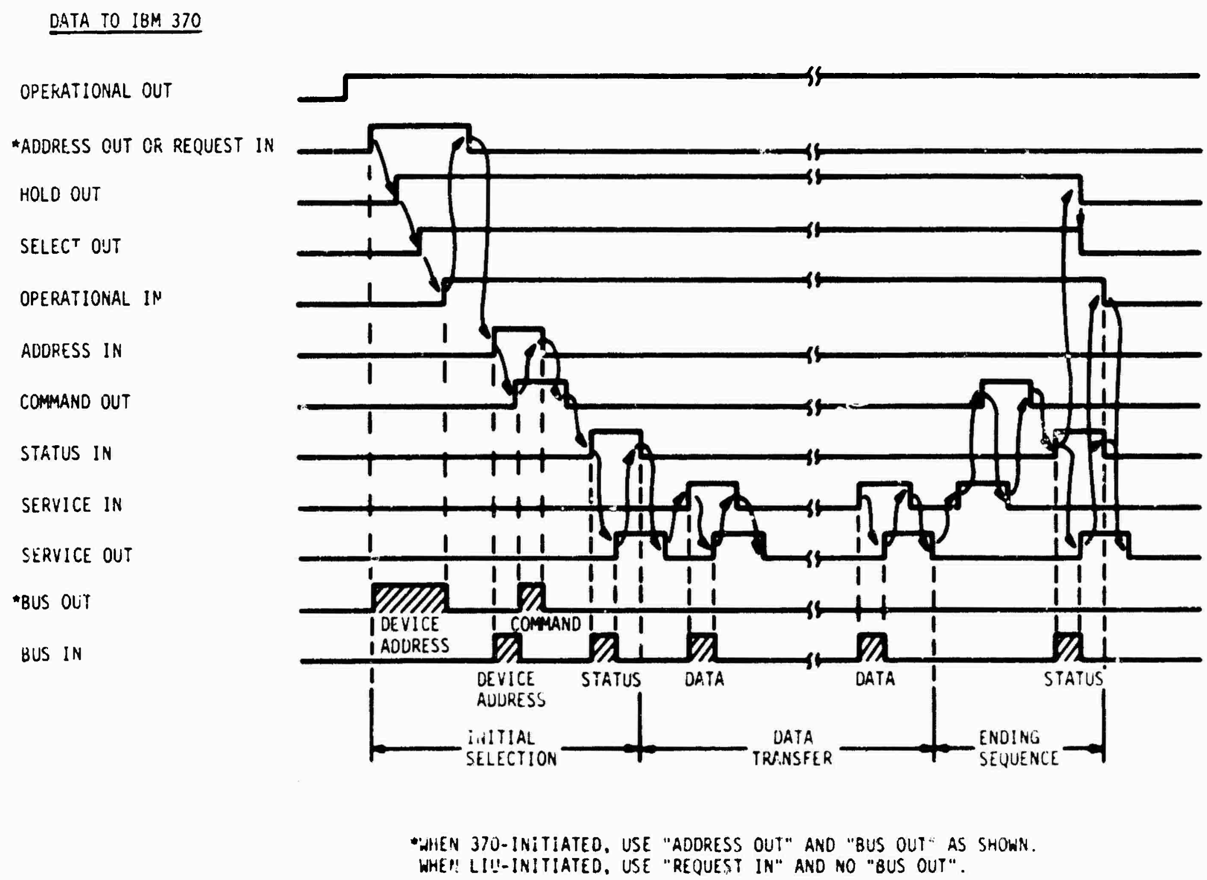


Figure 6-11. IBM channel timing (concl).

6.4.6 Conclusion. Much of the hardware for an adapter, such as the CPU, logic, DMA controller, and memory, can remain standard for most adapters, with the only changes being in the peripheral component employed. Software (program residing in the program memory) may be common to identical functions, such as for RS-232-C devices, but will experience changes from one function to another. Extra line driving/receiving capabilities and voltage level conversions will also be dependent on the application. Data word sizes can be accommodated by merely adding or deleting the number of peripheral components per adapter.

The two supplemental signals identified as ODR and IDR can eliminate operational problems associated with data block size information, as well as serve to provide initialization of each data transfer across the interface.

The initial requirements for the interface standard have guided this study to result in:

a. A single cost-effective design in basing the interface implementation on a microprocessor bus;

b. Consignment to an adapter module of all software and/or hardware modifications required for interface. This maintains rigidity of the LIU design; and

c. The concept of a DMA transfer across the interface in order to meet the 10 Mw/s criteria. This also prescribes a specially designed DMA controller using high-speed logic.

Adoption of the Intel 8085 microprocessor as the base for an LIU and SAU design assures the support (hardware and software) given to the most widely recognized and most extensively used microprocessor family in the industry. A readily apparent benefit is the modularity and flexibility inherent in an 8085-based adapter to the interface. Families of adapters can be developed, with the only changes being made in software and/or 8085-supported peripheral components. The growing universal understanding and acceptance of microprocessors supports their increased use in I/O structures for ADP devices.

7.0 FI IMPLEMENTATION OF TAF CENTERS

7.1 Communication system interfaces.

The FI can be implemented in all phases of TAF development represented by the five system control concepts (SCCs). The functions of interfacing elements of the FI vary with the development stage of the TAF equipment with which they will interface. If the FI is to be implemented in existing TAF centers, these equipments will not have been designed with compatible interfaces, e.g., the FI standard interface, nor will there be physical space within the shelters to house FI equipment. These factors make necessary communication adapters and FI electronics mounted external to shelters. However, as new TAF equipment is developed and as FI equipment is made available, communication adapters become unnecessary and many FI components will be mounted internally. This section defines the nature of the interface between the FI and TAF equipment for various phases of implementation.

Connectivities between the FI and TAC functions are shown for three major centers: The TACC, CRC/CRP, and DASC; and for one minor application, the ASRT and collocated FACP. Configurations of the centers were based on the system and traffic analyses performed in Task I. All SCCs are represented, and those features of each SCC which are significant to the design of the FI are included. Many shelters and equipments interface with the FI in identical, or similar ways. To avoid duplication, some centers, shelters, and equipments have not been included in the drawings.

It is assumed that those shelters and equipments in SCC-2 cannot be modified to interface with the FI. It may be possible to modify certain equipments in the SCC-3 or TRI-TAC time frame for the FI interface. All shelter and equipment in SCC-4A and SCC-4B will be designed for the FI interface. Therefore, the FI interface in SCC-2 is shown entirely external to each shelter, in SCC-4A and SCC-4B entirely within the shelters, and in SCC-3, the interface is either external or internal. Only in SCC-4A and SCC-4B will it be possible to configure a complete intrashelter bus.

The system control concepts from Task I were studied to determine which characteristics of each were most significant to the FI interface. A top-level drawing of the TACC, CRC/CRP, and DASC were made for each SCC showing the connectivity with major components of the FI. The most important shelters within each of the centers are shown in the next detail level. All of the signals interfacing with the communication adapters have been described in Section 2.3 and Table 2.8, Communication Interface by Functional Types, and Table 2.8, Interface Characteristics.

The quantities of each type of signal were derived from the traffic analysis, Section 2.4. A composite connectivity drawing of the TACC has been made for SCC-4A and 4B which shows both intrashelter and intershelter interface with the FI.

7.1.1 TACC/AFCH, SCC-2. Shelters in the TACC/AFCH center, SCC-2, are shown in Figure 7-1 interconnected by the FI bus. The interface with the FI is made through an interface module (IM) which is attached to the external wall of each shelter. Each IM contains LIUs, an LICU and an EIU. All intershelter communication signals interface with the FI at the IM and are carried on the bus.

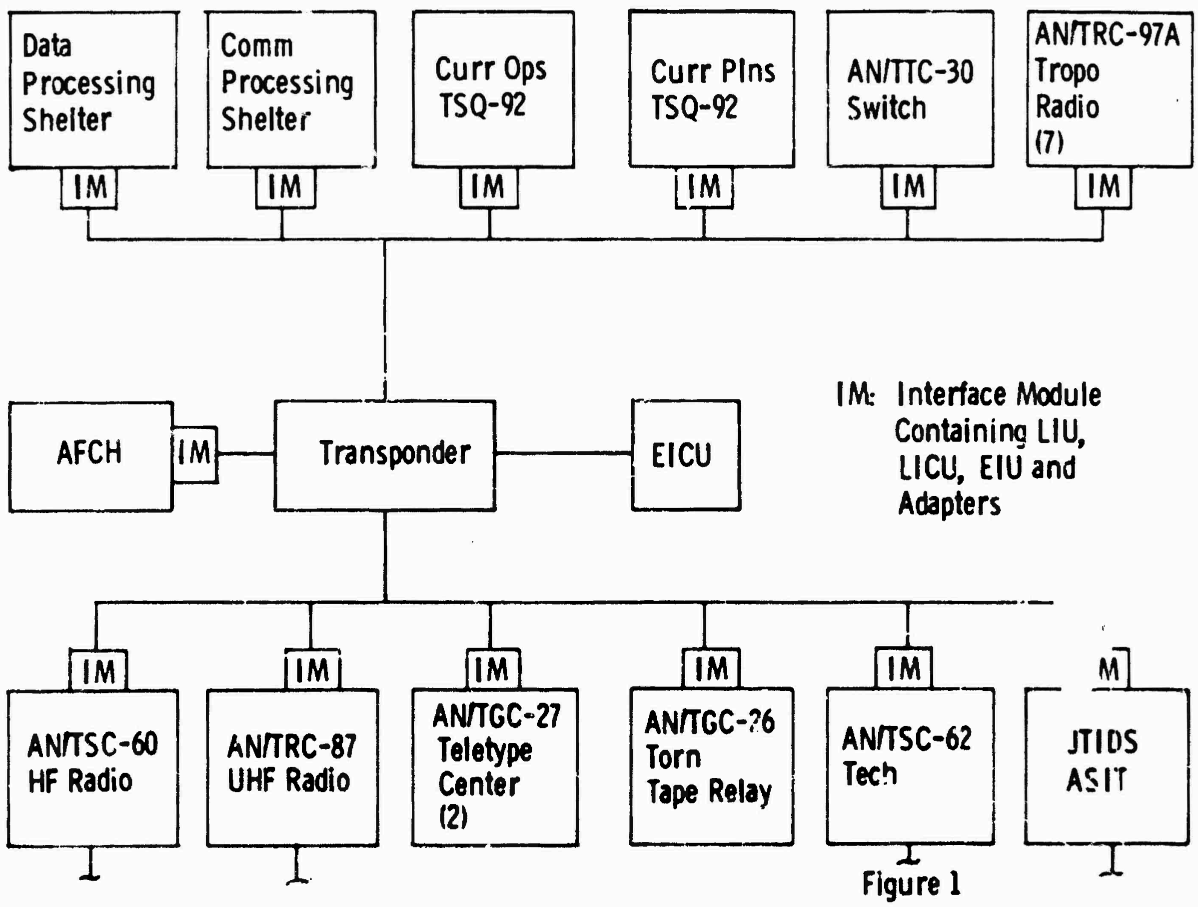


Figure 7-1. TACC/AFCH (SCC-2).

7.1.1.1 Communication processor shelter. Digital circuits enter the COM PROCESSOR shelter from the communication adapters as FSK - modulated quasi-analog signals. Refer to Figure 7-2. Quasi-analog signals use analog voice adapters. WWMCCS and AUTODIN circuits enter the TACC via teletype over these circuits and TADIL-A, TADIL-B, DDL, the TIPI-DC/SR link, and links from the JTIDS ASIT enter the TACC via the COMM PROCESSOR. These communication circuits enter the TACC center via radio or cable and are routed over the bus to the AN/TSC-62 technical control shelter and then over the FI to the COMM PROCESSOR shelter where they appear as the 33 digital circuits shown.

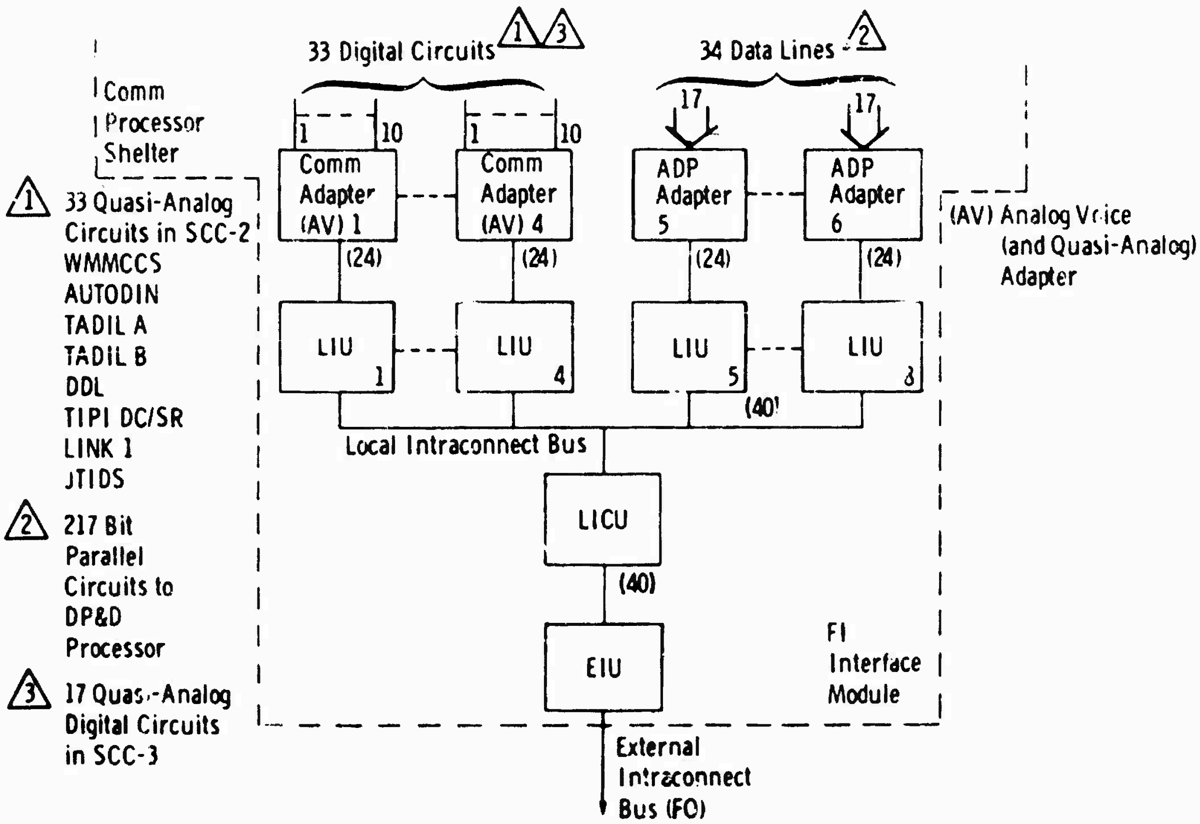


Figure 7-2. TACC-Comm processor communications circuits (SCC-2&3).

The CP in the COMM PROCESSOR shelter drives the CP in the Data Processing and Display shelter over two 17-bit parallel circuits. These circuits are handled by ADP (CS) type adapters.

7.1.1.2 Current operations shelter. The Current operations shelter uses 88 analog telephone circuits that access TAC over the FI bus as shown in Figure 7-3. The circuits require 9 analog voice (AV) adapters. The instruments are TA-720 and TA-341 telephones with TA-741 stored address units or C-7766 6-W radio set controls. All circuits terminate at the AN/TTC-30 switch or AN/TSC-62 tech control.

7.1.1.3 Current plans shelter. The Current plans shelter (Fig. 7-4) uses 152 analog telephone circuits in the same manner as described for the Current Ops shelter.

7.1.1.4 Automatic switch, AN/TTC-30. The AN/TTC-30 automatic switch handles 422 analog circuits using 43 AV communication adapters (Fig. 7-5).

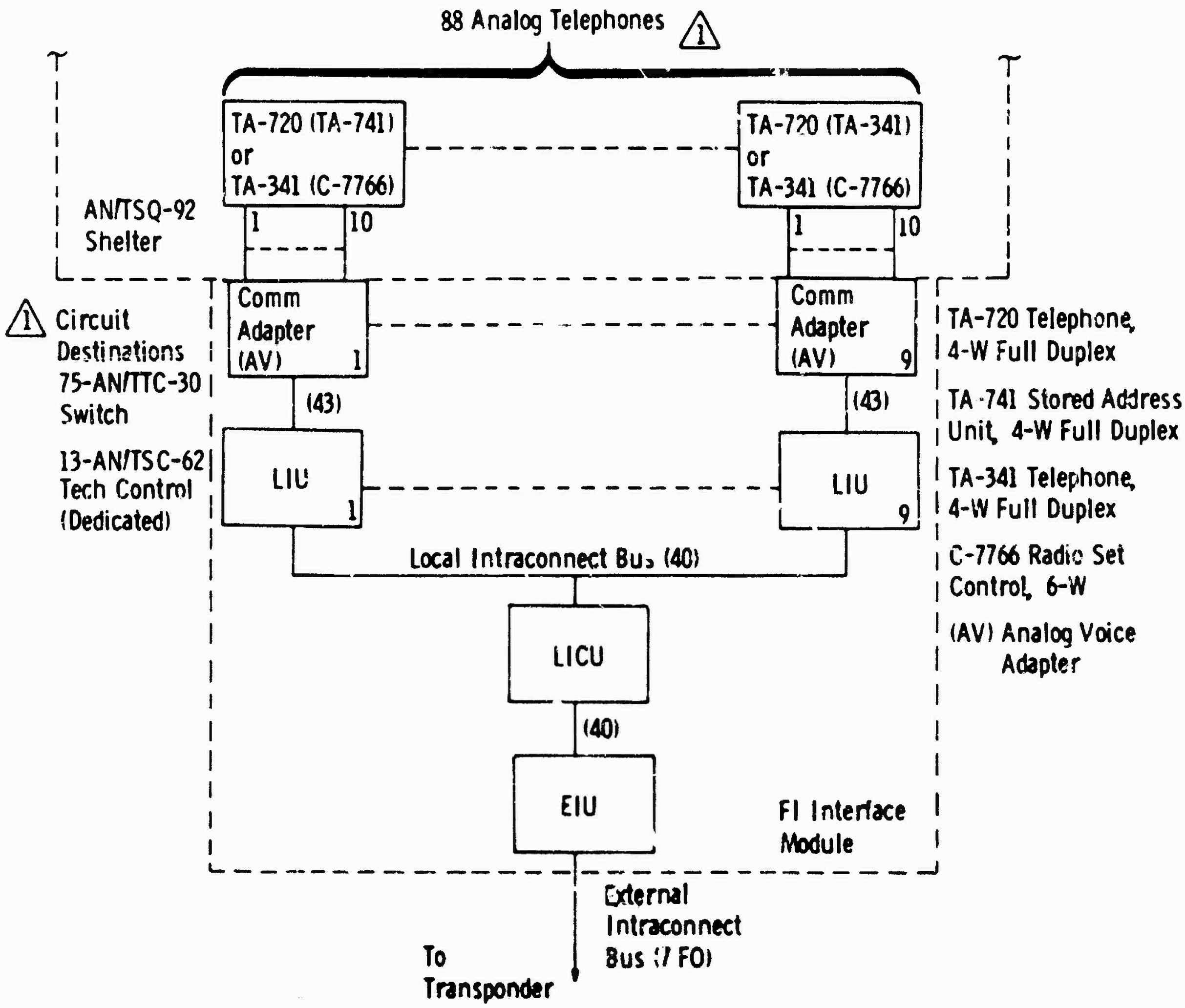


Figure 7-3. TACC/AFCH current ops communication circuits (SCC-1 & 2).

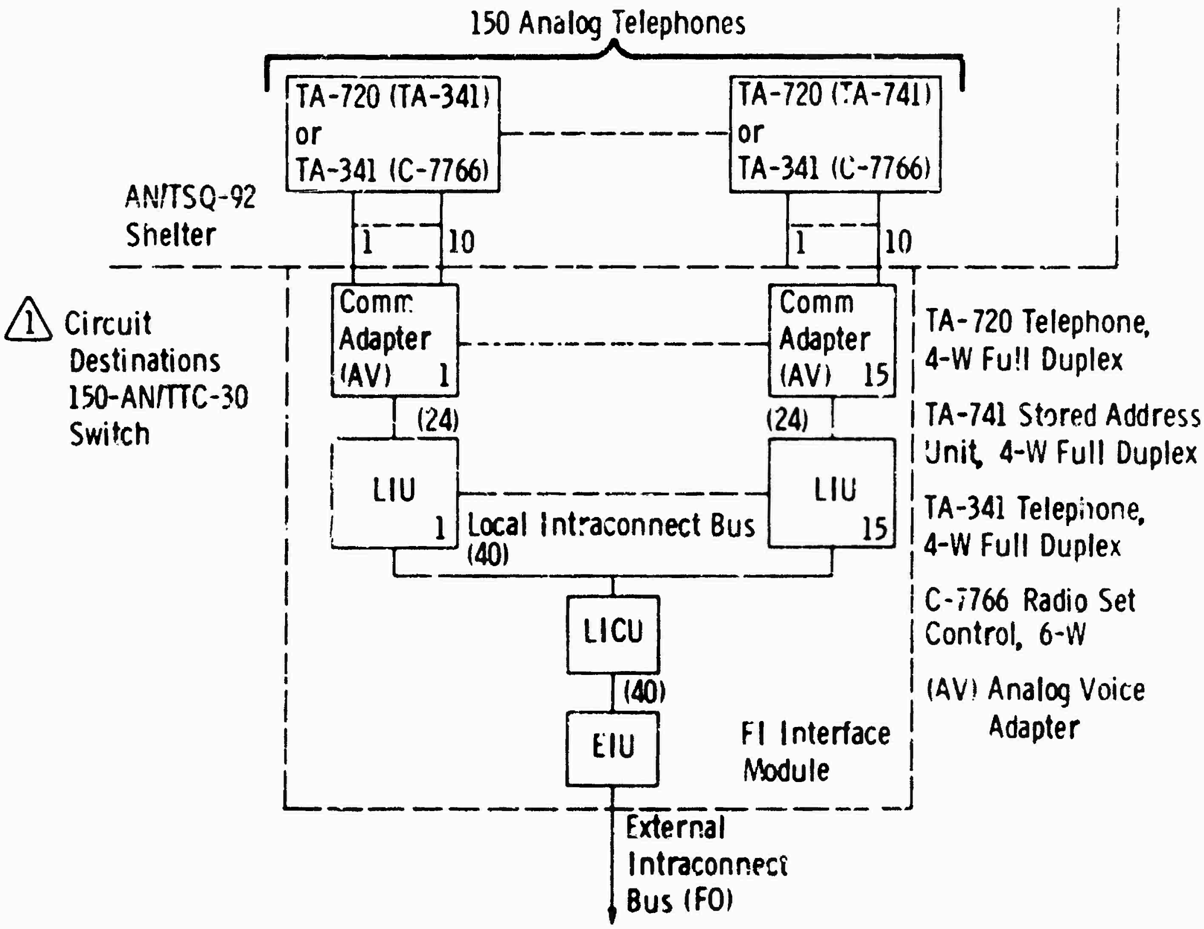


Figure 7-4. TACC/AFCH current plans communications circuit (SCC - 1 & 2).

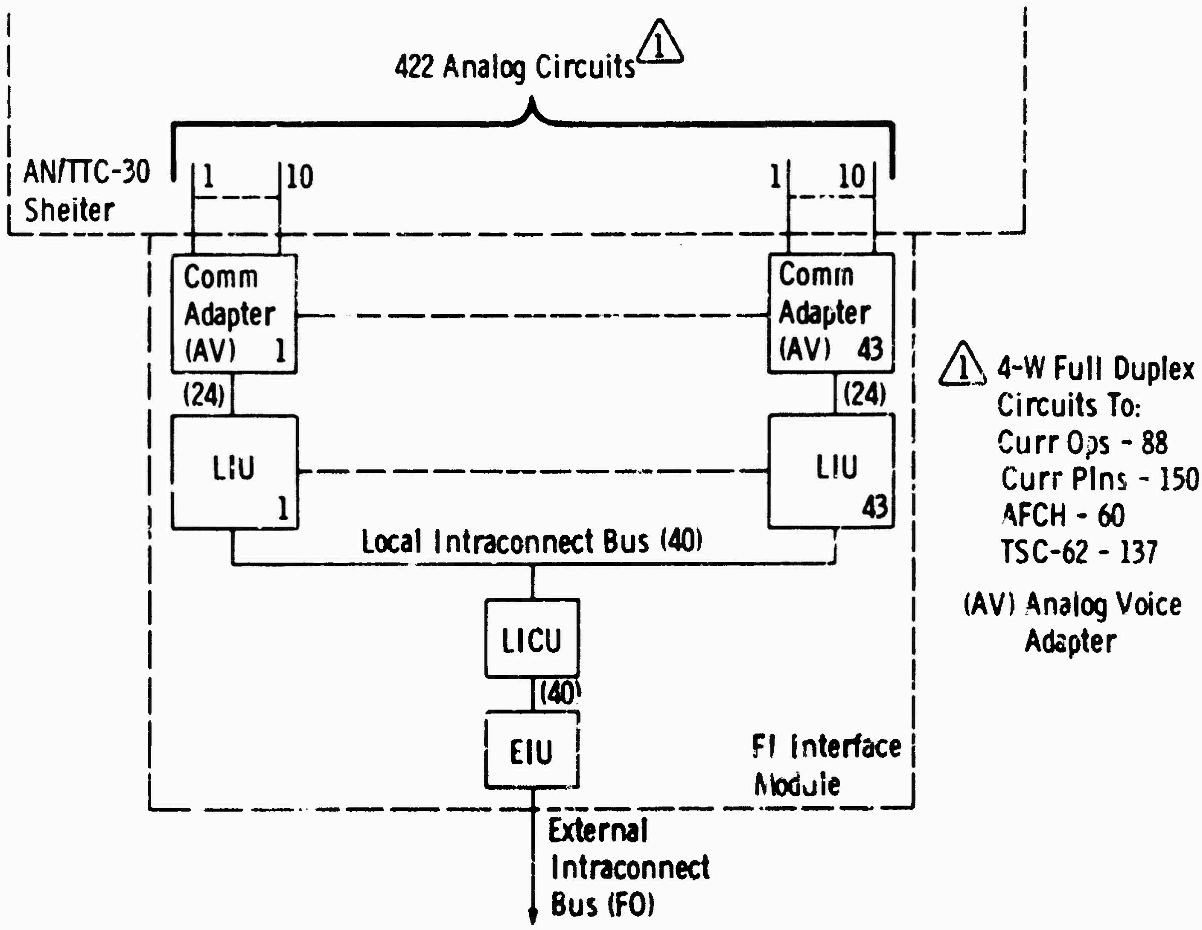


Figure 7-5. AN/TTC-30 automatic switch - TACC center communications circuits (SCC - 1 & 2).

7.1.1.5 Technical control shelter, AN/TSC-62. The AN/TSC-62 technical control shelter provides access to 370 analog telephone circuits via 37 AV communication adapters, and 84 digital teletype and FAX circuits via 9 AV adapters (Fig. 7-6). The latter 84 circuits are quasi-analog signals which use analog voice circuits.

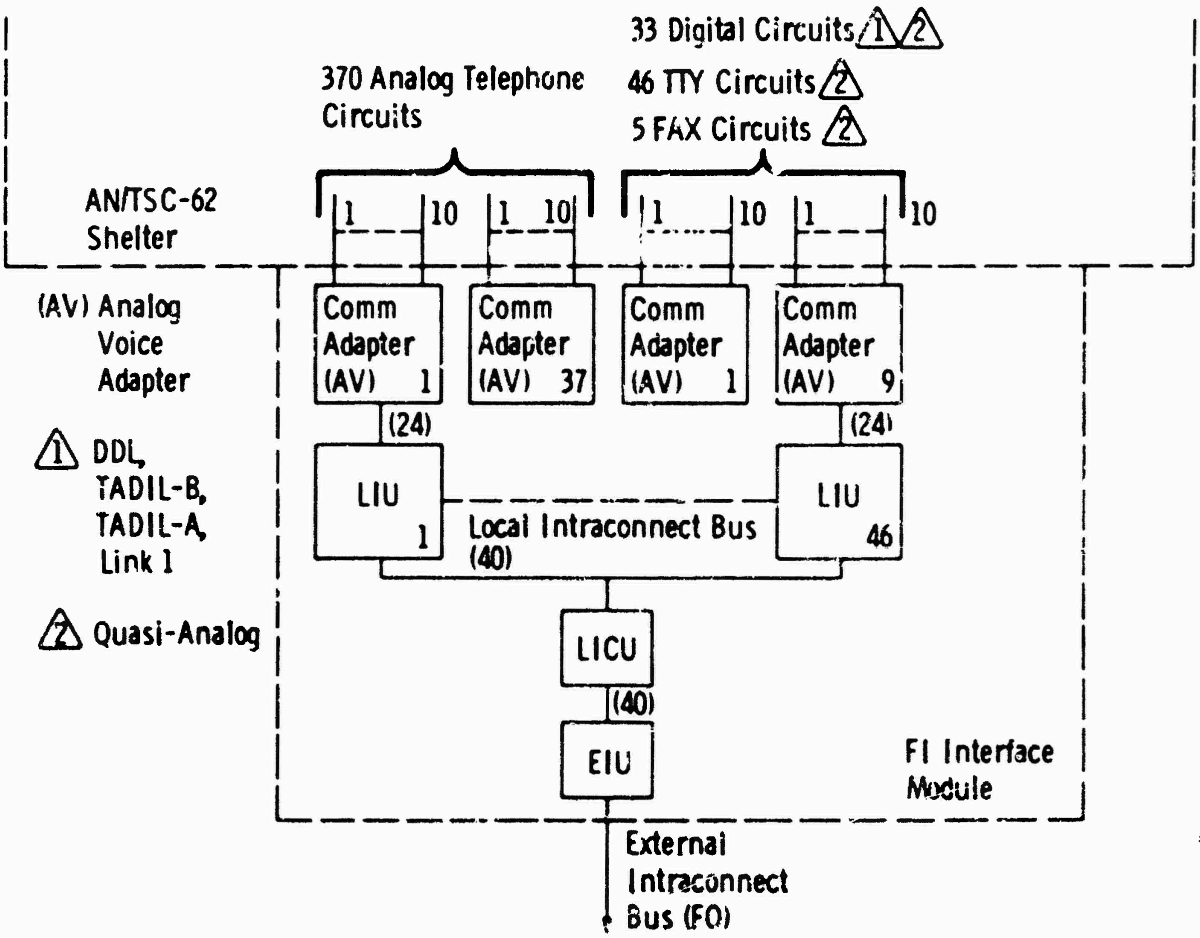


Figure 7-6. AN/TRC-97 tropo radio - TACC center communications circuits (SCC 2).

7.1.1.6 Tropo radio shelter, AN/TRC-97. The AN/TRC-97 Tropo Radio interfaces 160 analog voice circuits and 11 quasi-analog digital circuits with the FI using 18 AV communication adapters (Fig.7-7).

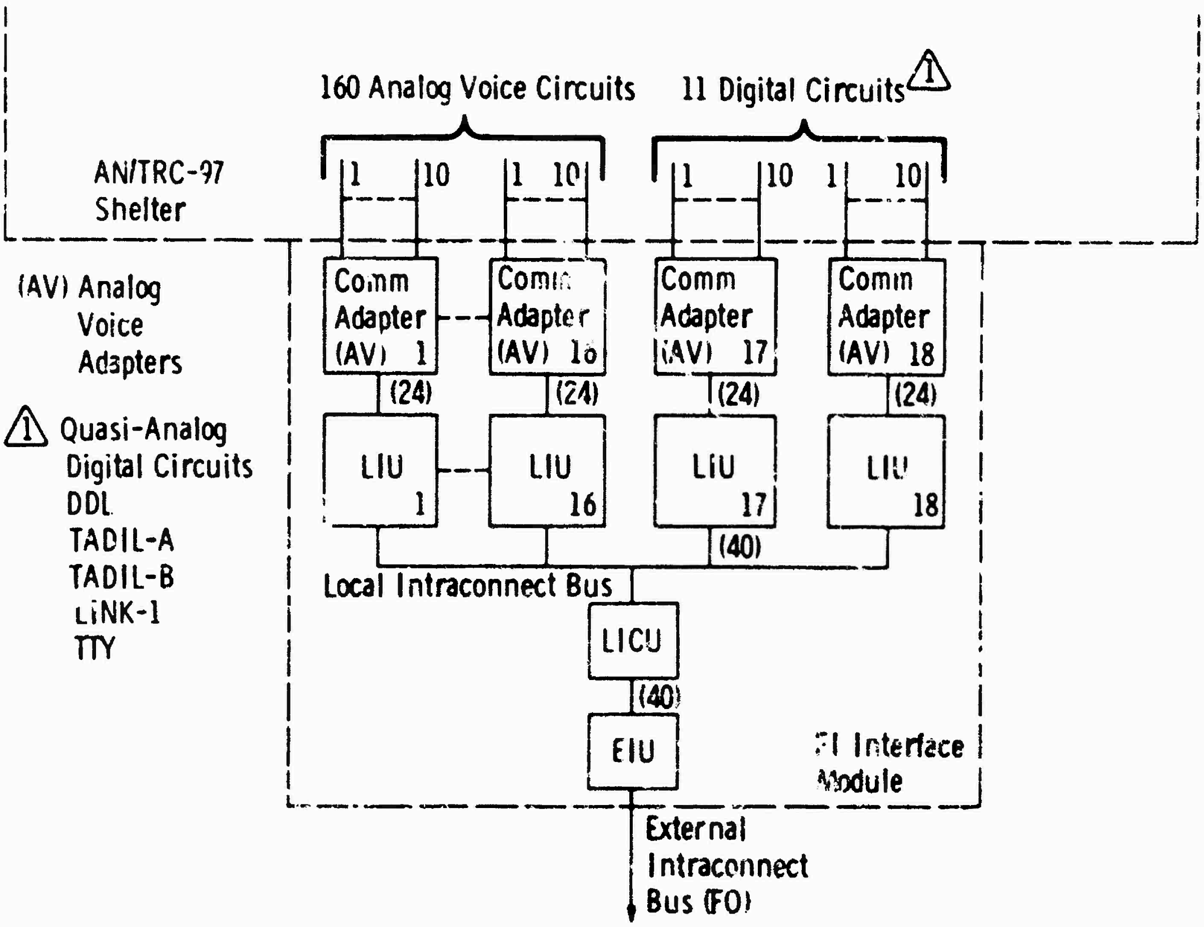


figure 7-7. AN/TRC-97 tropo radio - TACC center communications circuits (SCC 2).

7.1.1.7 JTIDS Adaptable Surface Interface Terminal (ASIT). The JTIDS ASIT Shelter interfaces 15 quasi-analog digital circuits with formatted message entry (FME) modems and up to 10 analog voice circuits with unformatted message entry (UME) modems (Fig. 7-8). A maximum of 25 formatted and unformatted messages can be accommodated by the SCC-2 version of the JTIDS ASIT.

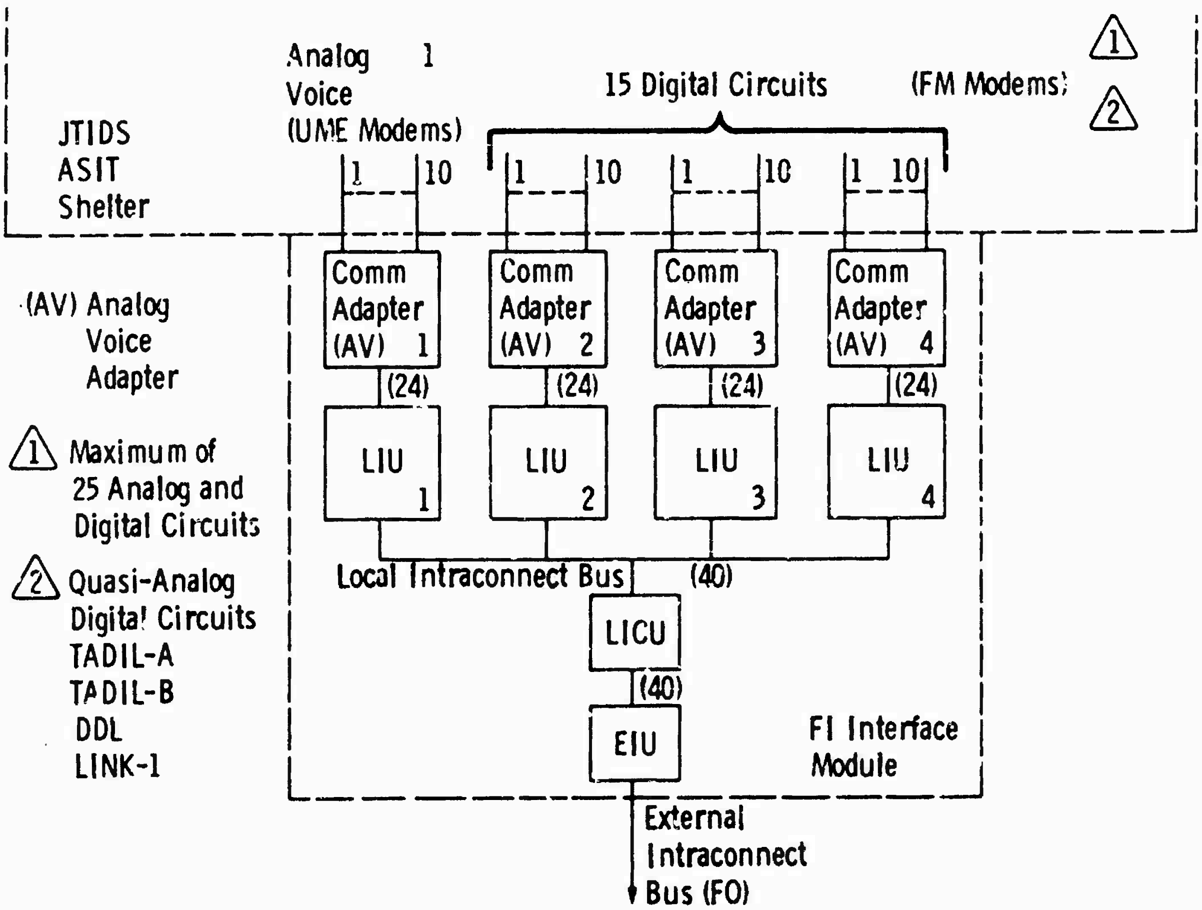


Figure 7-8. JTIDS ASIT - TACC center communications circuits (SCC-2).

7.1.2 TACC/AFCH SCC-3. The shelters in the TACC/AFCH center, SCC-3, are shown in Figure 7-9 interconnected by the FI bus. SCC-3 introduces TRI-TAC equipment to TAC. TRI-TAC equipment is characterized by digital telephones (DSVTs and DNVTs) and digital multiplexing and transmission equipment using the family of digital group multiplexers and models. In those instances when the design of a particular shelter type can accommodate the adapter, LIU, LICU, and IUE internal to the shelter wall, they will be mounted internally. Otherwise these units will be mounted externally as they are in SCC-2 configurations.

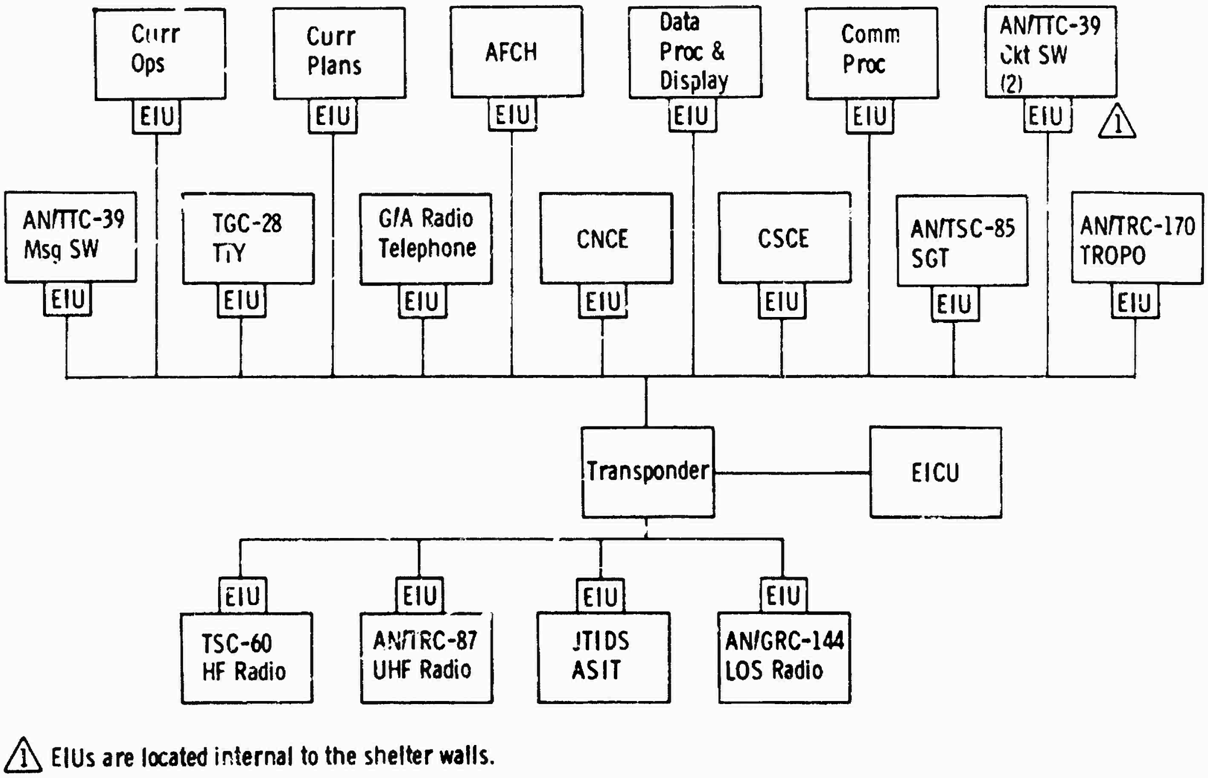


Figure 7-9. TACC/AFCH (SCC-3).

When mounted internally, it will be possible in many cases to interconnect the adapters directly to the digital loop equipment and eliminate the necessity for group multiplexers and modems. DGM multiplexers and modems will still be required for forming and transmitting intercenter groups. This feature is illustrated in Figure 7-10.

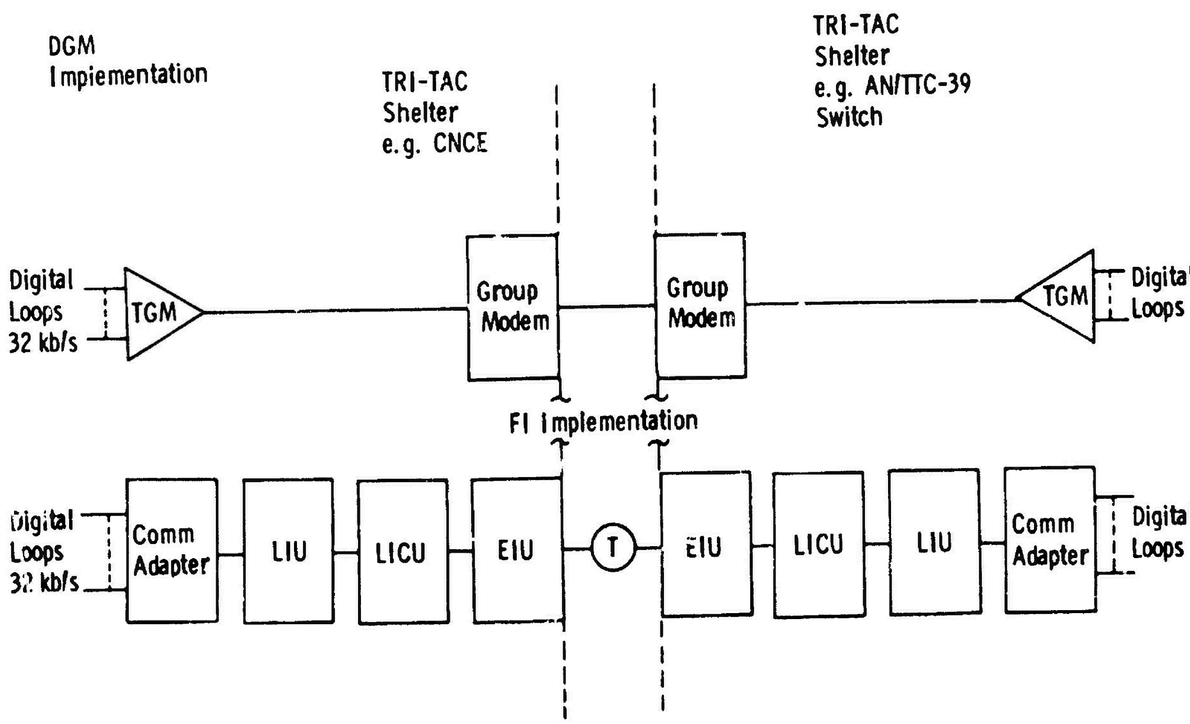


Figure 7-10. Replacement of multiplexing and transmission functions by FI equipment.

7.1.2.1 Operations central SCC-3. Current Operations and Current Plans in separate shelters in SCC-2 have been combined in SCC-3 for convenience. They may, in fact, be deployed in separate shelters in in SCC-3 as well. DSVT/DNVT telephones replace 75 analog telephones (Fig. 7-11. DSVT/DNVTs use LSSD communication adapters. Also included in Figure 7.1-11 are the 17-bit parallel data circuits used to drive the dipslay consoles from the data processing and display function. These use ADP adapters. 50 analog telephones, using AV adapters, are retained in SCC-3.

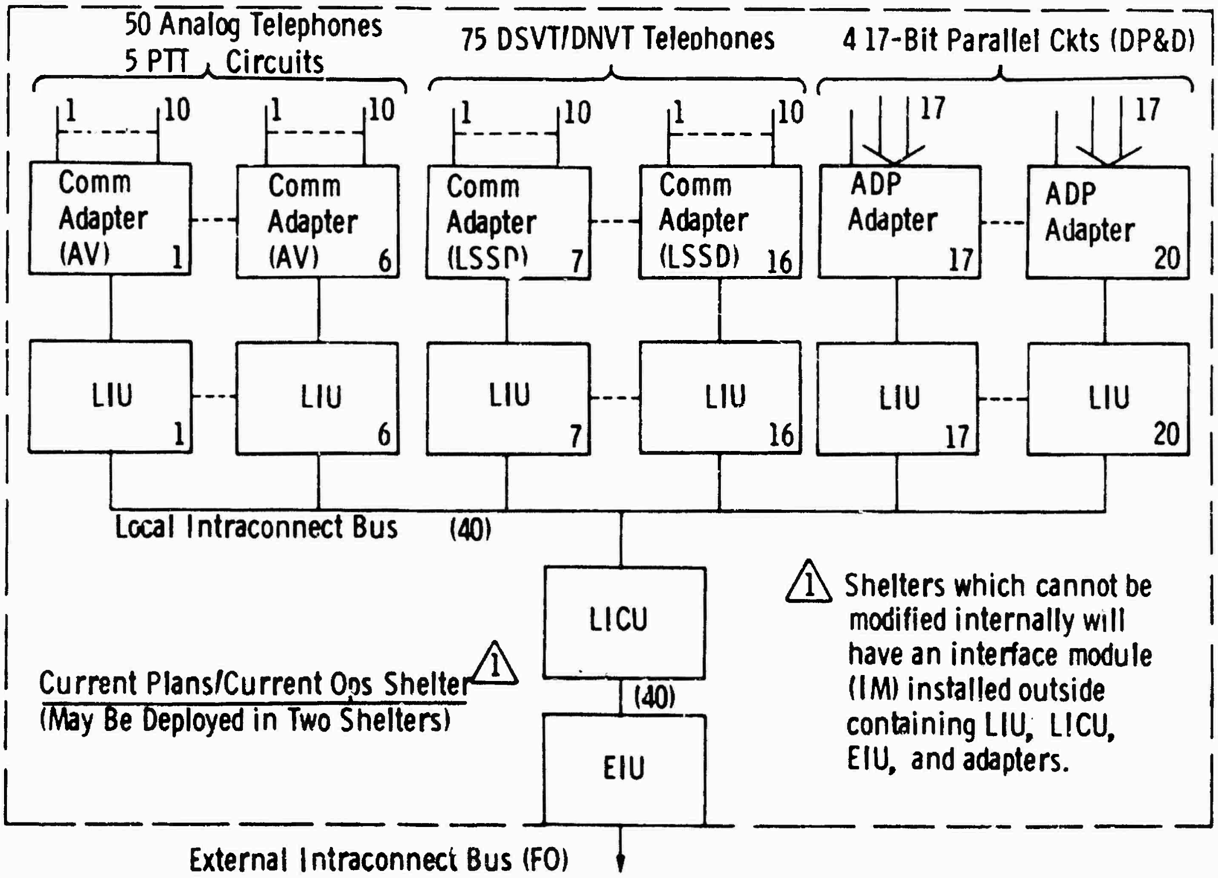


Figure 7-11. TACC/AFCH - operations central (curr ops-curr plns) communications circuits (SCC-3).

7.1.2.2 Communication processor shelter, SCC-3. The communication processing shelter remains the same in SCC-2, Figure 7-2, except for a reduction in digital circuits (quasi-analog) from 33 to 17, due to the increased dependence on 32 kb digital communication from TRI-TAC equipment.

7.1.2.3 Tropo radio, SCC-3. The tropo radio interfaces 255 analog circuits, 22 teletype, and 21 data circuits through 30 AV adapters, and 17 digital trunk groups through HSSD adapters (Fig. 7-12).

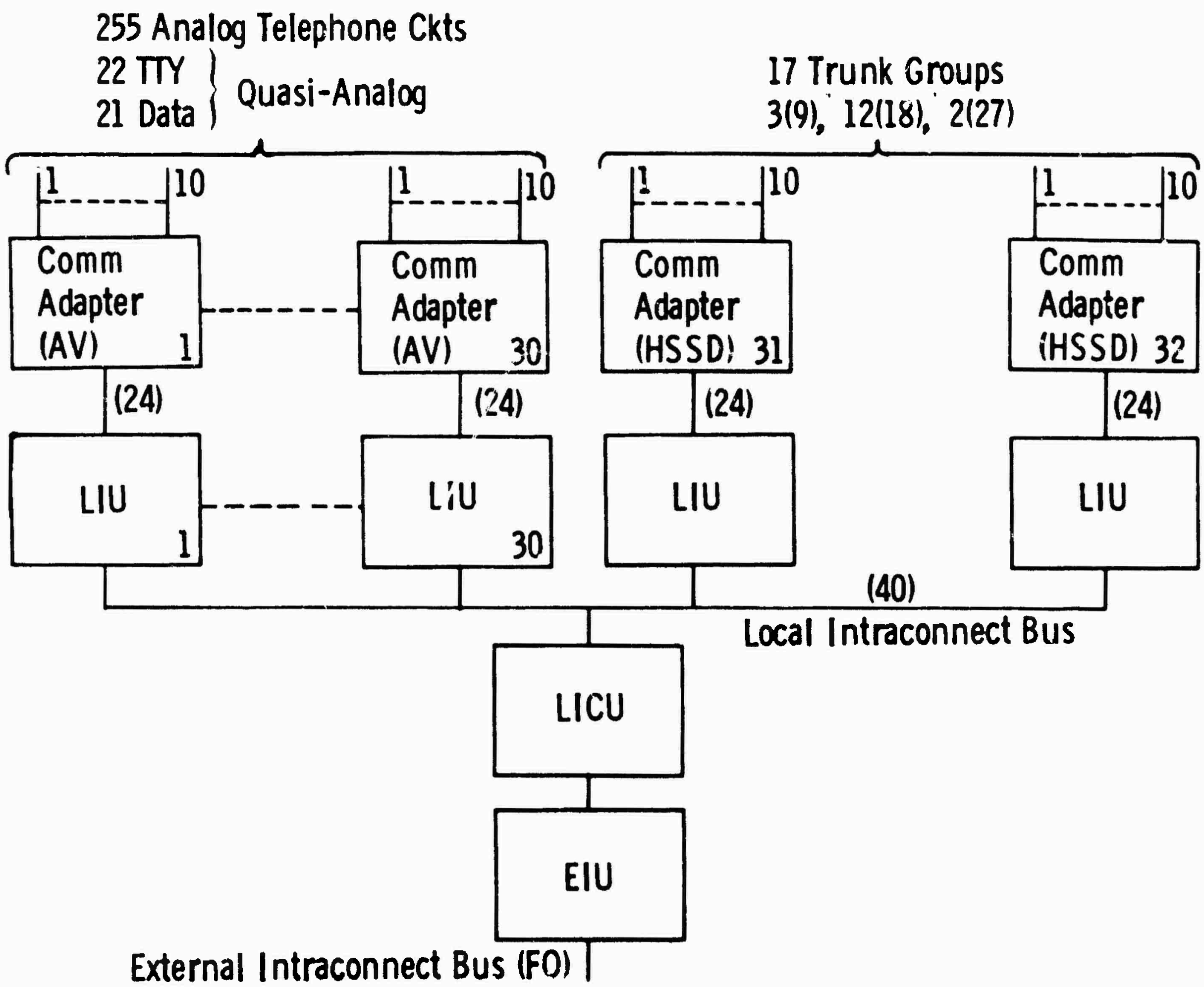


Figure 7-12. TACC/AFCH - AN/TRC 170 tropo communication circuits (SCC-3).

7.1.2.4 Technical Control Shelter, CNCE, SCC-3. The CNCE interfaces 314 analog telephone circuits, 52 teletype and 69 data circuits through 3 LSSD adapters, and 39 digital trunk groups through 4 HSSD adapters (Fig. 7-13). When the FI can be installed, as shown in Figure 7-13, within the shelter, the need for data multiplexers and data orderwire diphase modems is eliminated in the same way that trunk goup mulitplexers (TGM) and group models are eliminated in the TACC in Figure 8-10. Also, any combining of the 39 trunk groups which may have been required for intracenter transmission would not now be necessary. Some number of TGMs would, therefore, not be needed when the FI is implemented. In addition, there is no need for any group modems in the FI implementation.

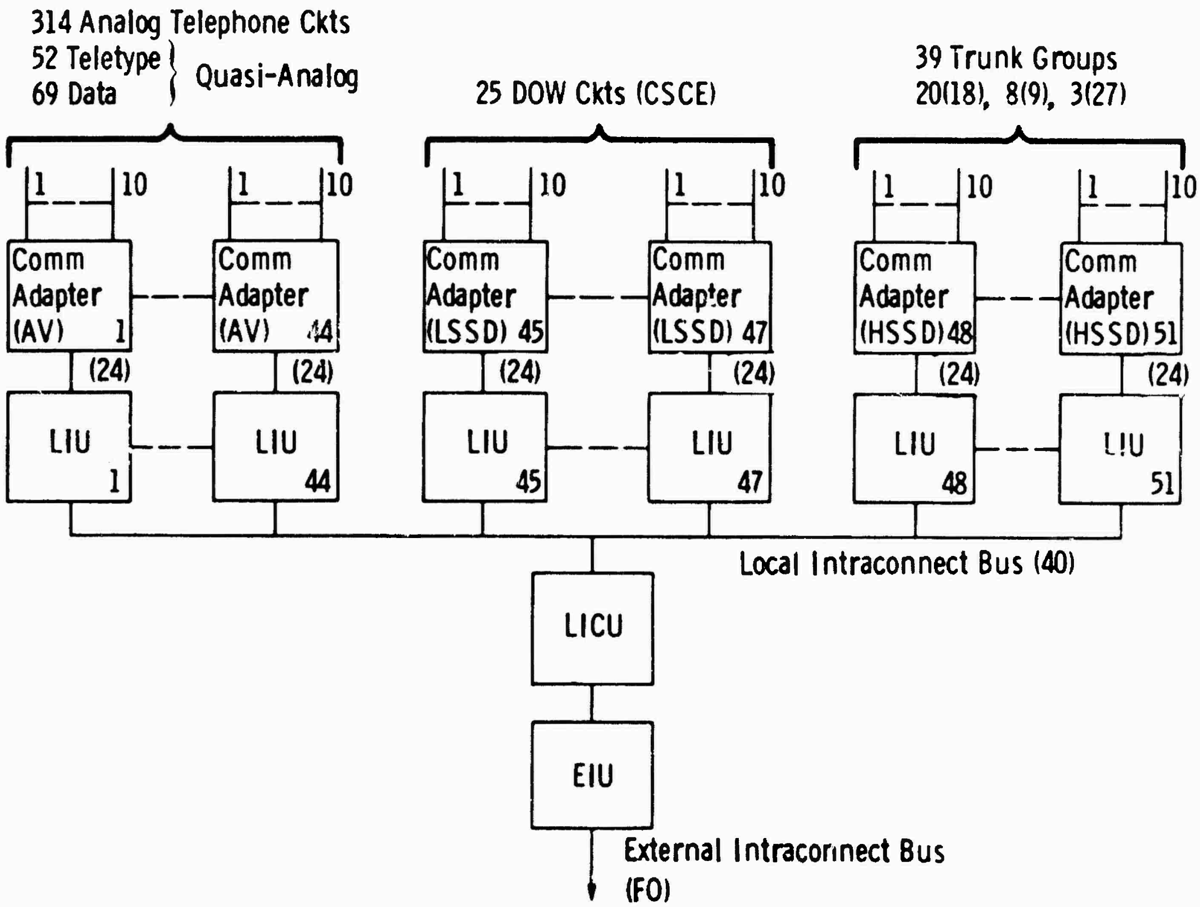


Figure 7-13. TACC/AFCH - AN/TSQ-111 tech control (CNCE) communications circuits.

7.1.2.5 AN/TTC-39 Automatic switch, SCC-3. The AN/TTC-39 automatic switch interfaces 163 analog circuits through 17 AV adapters, 101 digital telephone loops through 11 LSSD adapters, and 11 digital groups through 2 HSSD adapters (Fig. 7-14). DGM Loop Group Mulitplexers, Trunk Group Multiplexers loop modems, and group modems are eliminated by the FI for the same reasons as were stated in earlier paragraphs and Figure 7-10.

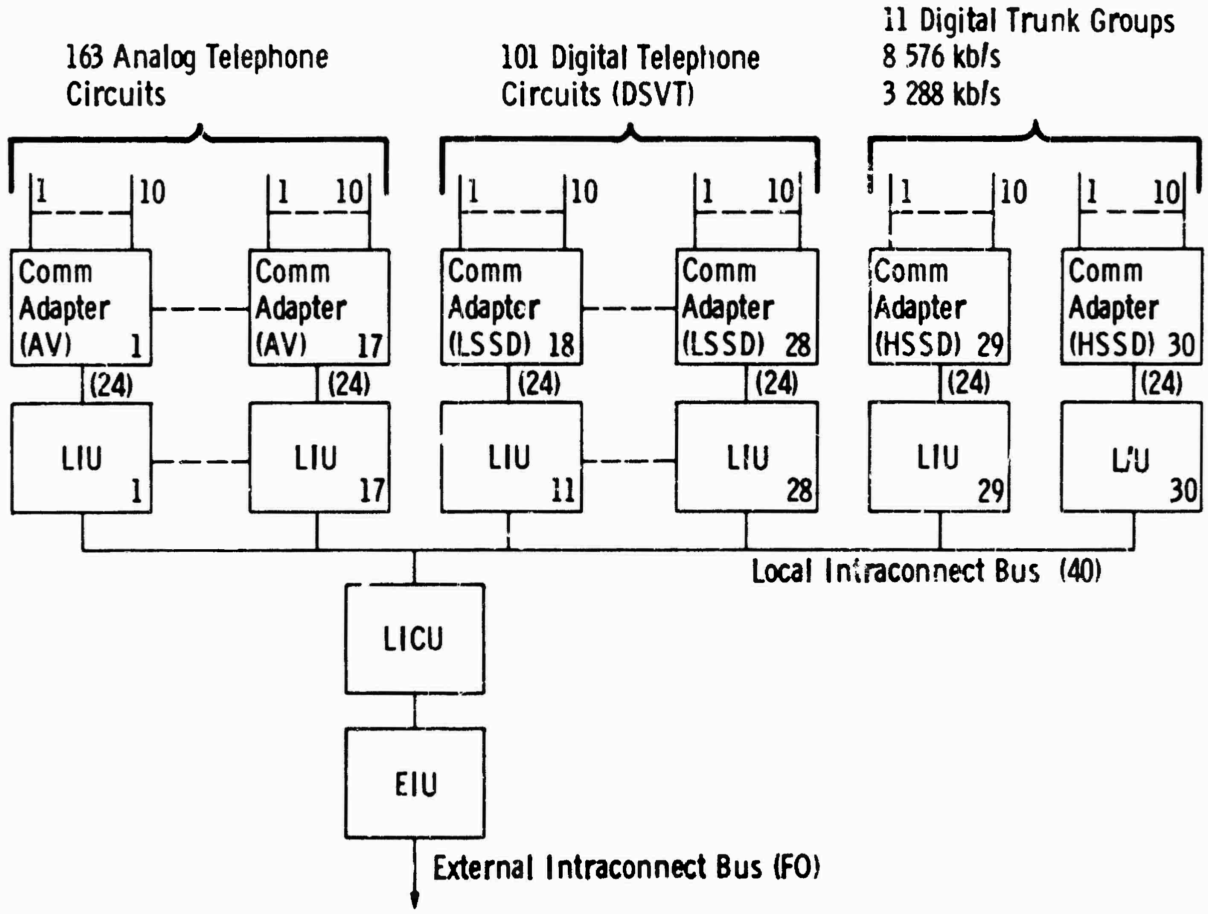


Figure 7-14. TACC/AFCH - AN/TCC-39 switch communications circuits (SCC-3).

7.1.3 TACC, SCC-4A. In the SCC-4A configuration of TACC, the major impact is the addition of more processors and processor-to-processor data links. The ADP changes are discussed in Task I Final Report and in ADP sections of this analysis. Additional data links are necessary from the FRRP and drone control facility to accommodate these, and an E-3A A/C TV link is added to TACC (Fig. 7-15). This implementation is shown in the satellite ground terminal (SGT) and revised JTIDS ASIT.

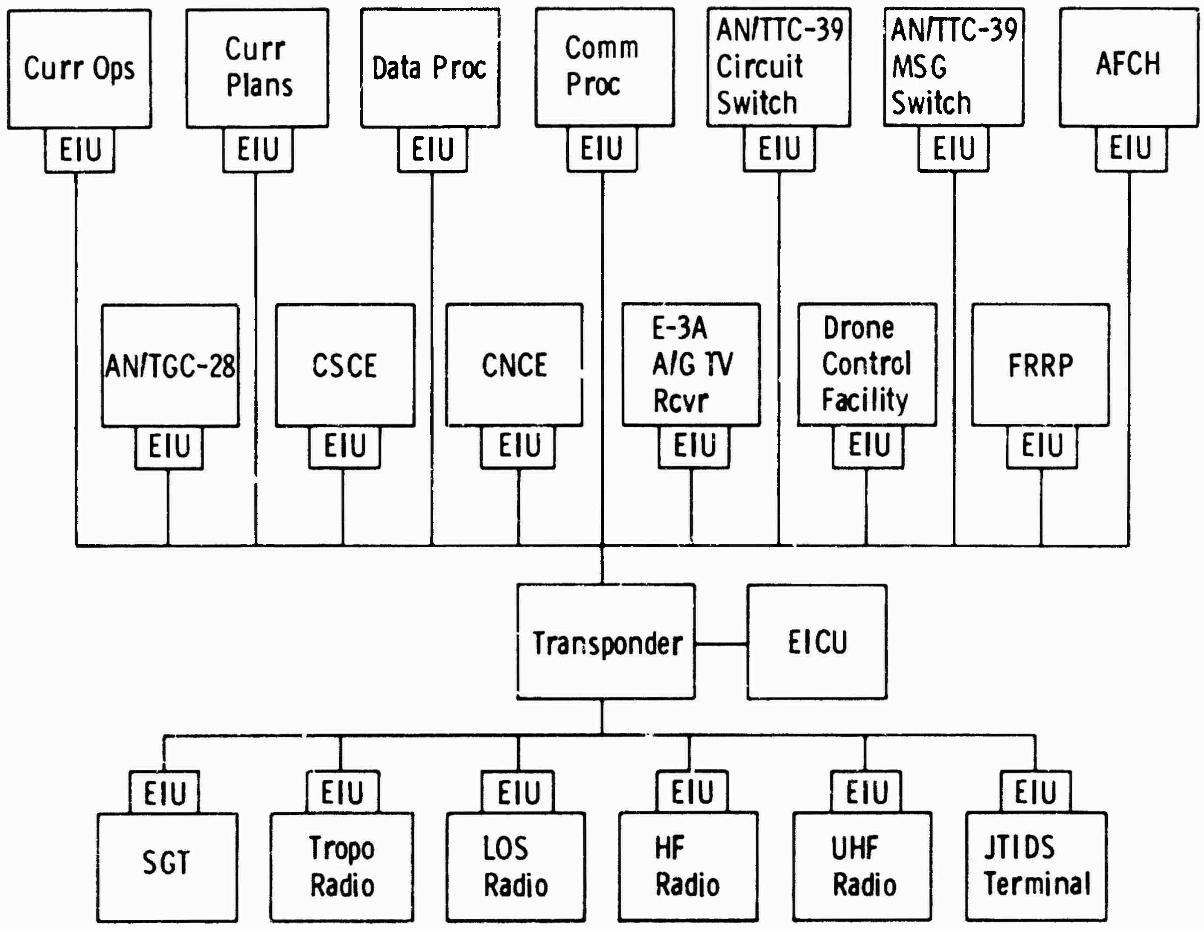


Figure 7-15. TACC (SCC-4A).

FI components are mounted internal to the shelters in SCC-4A and interfacing units are assumed to be designed for optimum interface with the FI. Communication adapters are still necessary in this configuration because the conversion from the communications device to the standard interface, required by the IIU, is more practically done in adapters rather than in the communication devices themselves. This is not true for ADP devices where the standard interface is more practically included in the ADP devices and ADP adapters are not necessary.

7.1.3.1 Satellite Ground Terminal, SGT, SCC-4A. The SGT interfaces 2 trunk groups in one HSSD adapter, 2 32 kb/s circuits in one LSSD adapter, and a 3.5 MHz TV video circuit through an AS adapter (Fig. 7.16). The E-3A TV receiver is assumed for this purpose to be located in or near the SGT, however, its location has not been verified.

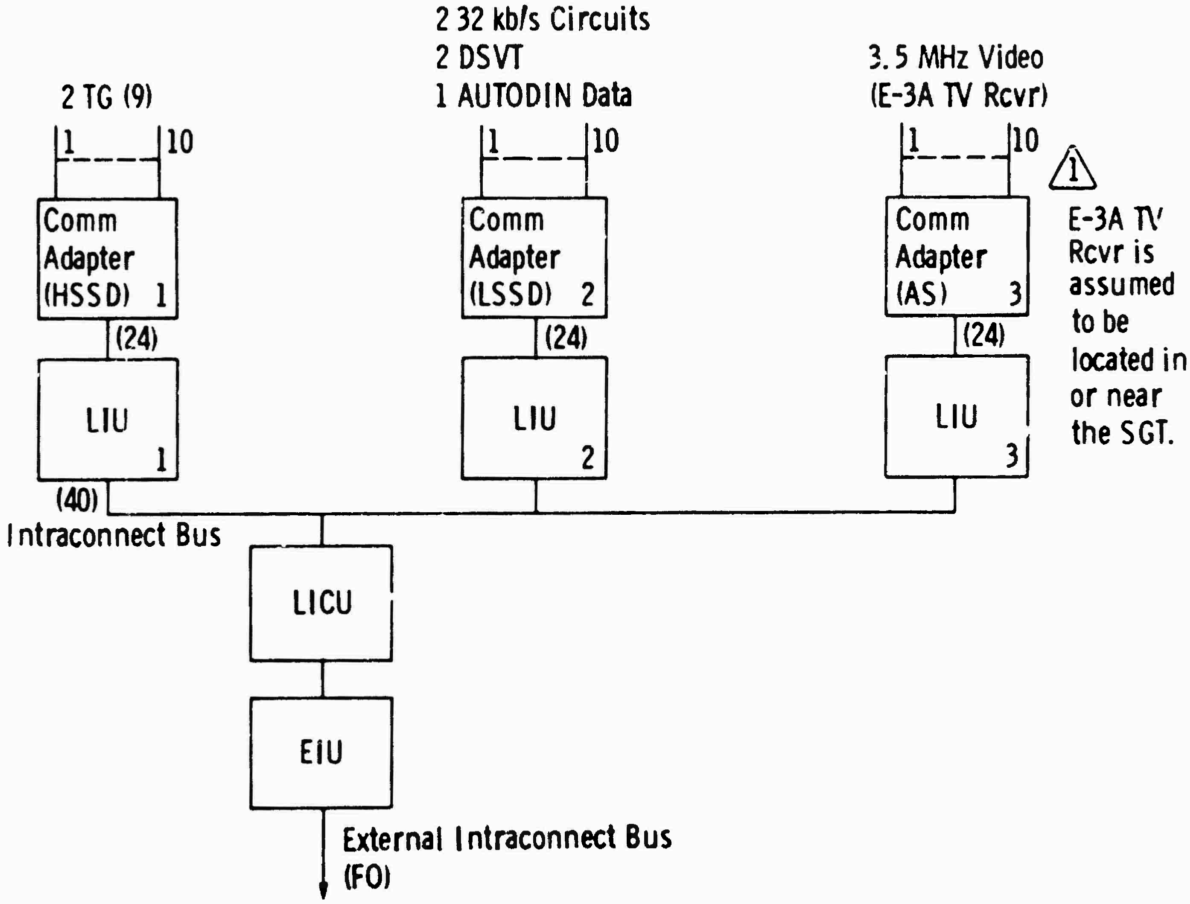


Figure 7-16. TACC/AFCH - satellite ground terminal communications circuit.

7.1.3.2 JTIDS ASIT, SCC-4A. The JTIDS ASIT interfaces 17 G/A/G voice circuits at 32 kb/s, each through 2 LSSD adapters, and 2 quasi-analog data circuits through one AV adapter (Fig. 7-17).

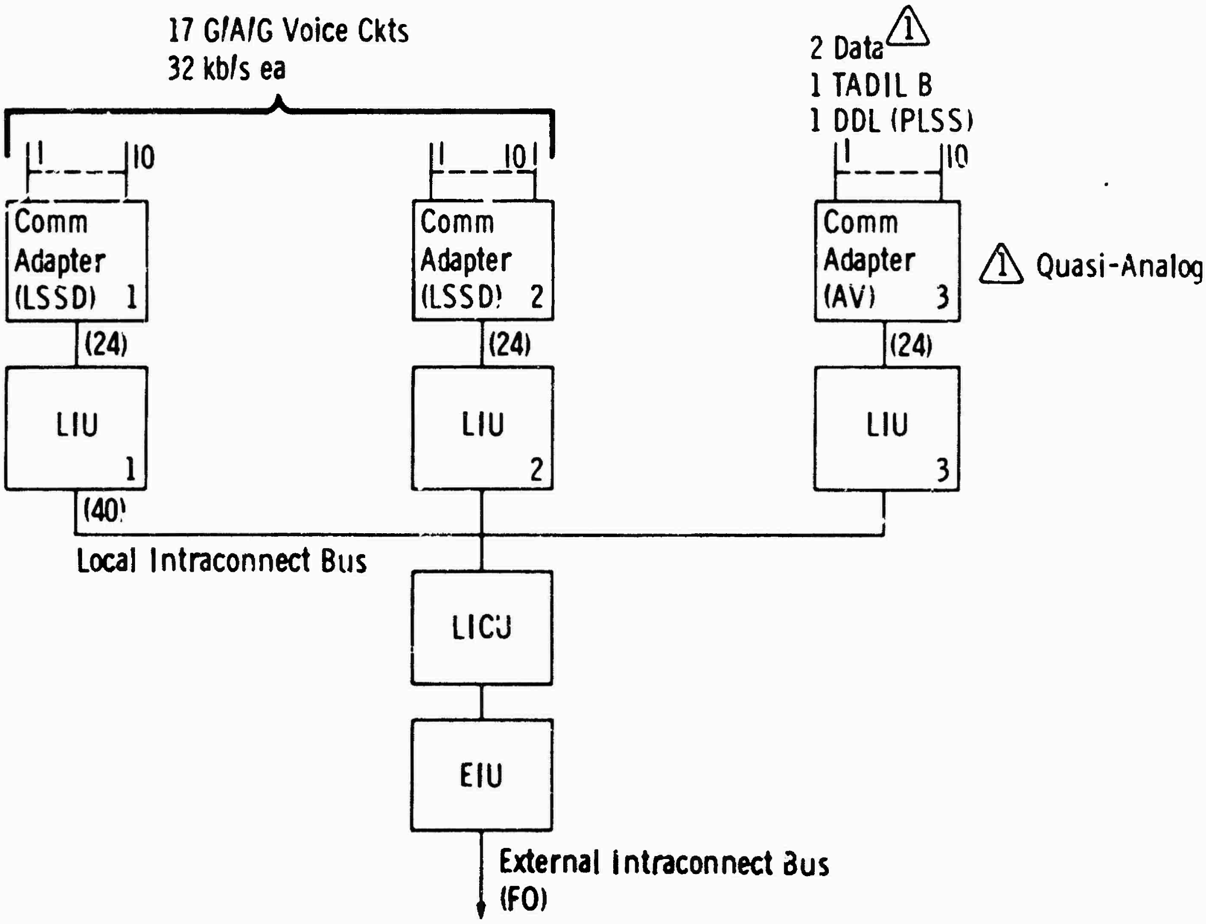


Figure 7- 17. TACC/AFCH - JTIDS ASIT (SCC-4A).

7.1.4 TACC, SCC-4B. SCC-4B introduces the concepts of netted radios to the TACC (Fig. 7-18). The G/G radio links that were previously provided by TROPO and LOS radios will be dispersed in a network of medium-range radios. The network will provide alternate and redundant RF paths to offset the ARM threat and to provide self-healing characteristics. Transmissions on the network are controlled by a network controller. It is assumed that one 16-kb/s data link from the controller to each radio is sufficient for the requirement and that the network controller will be located in a separate shelter at radio park at the top of the hill.

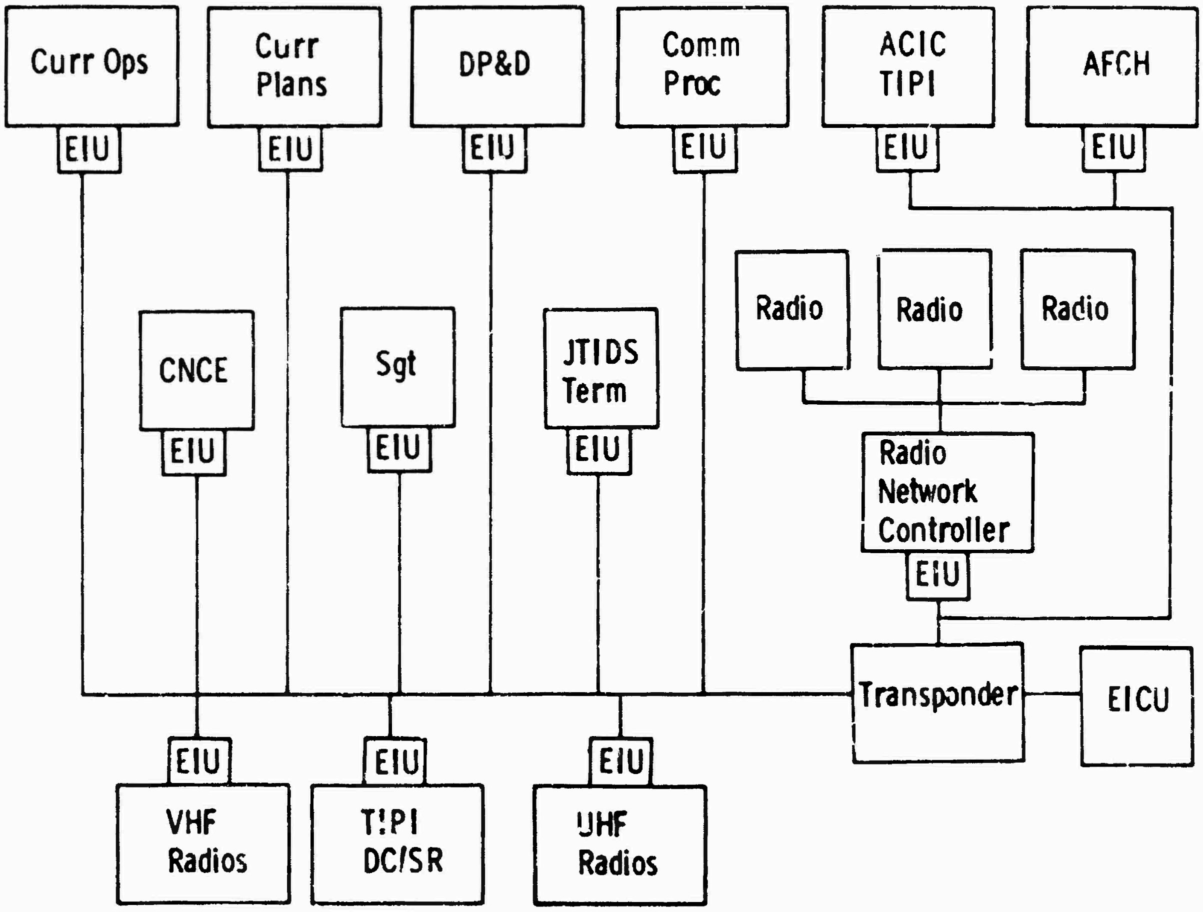


Figure 7-18. TACC (SCC -4B).

7.1.4.1 Radio network controller shelter, SCC-4B. The radio network controller shelter will require a maximum of 10 16 kb/s radio control circuits using one LSSD communication adapter, 2 orderwire, 2 FAX; and 4 data circuits using one LSSD communciation adapter; and 7 trunk groups using 1 HSSD communication adapter (Fig. 7-19).

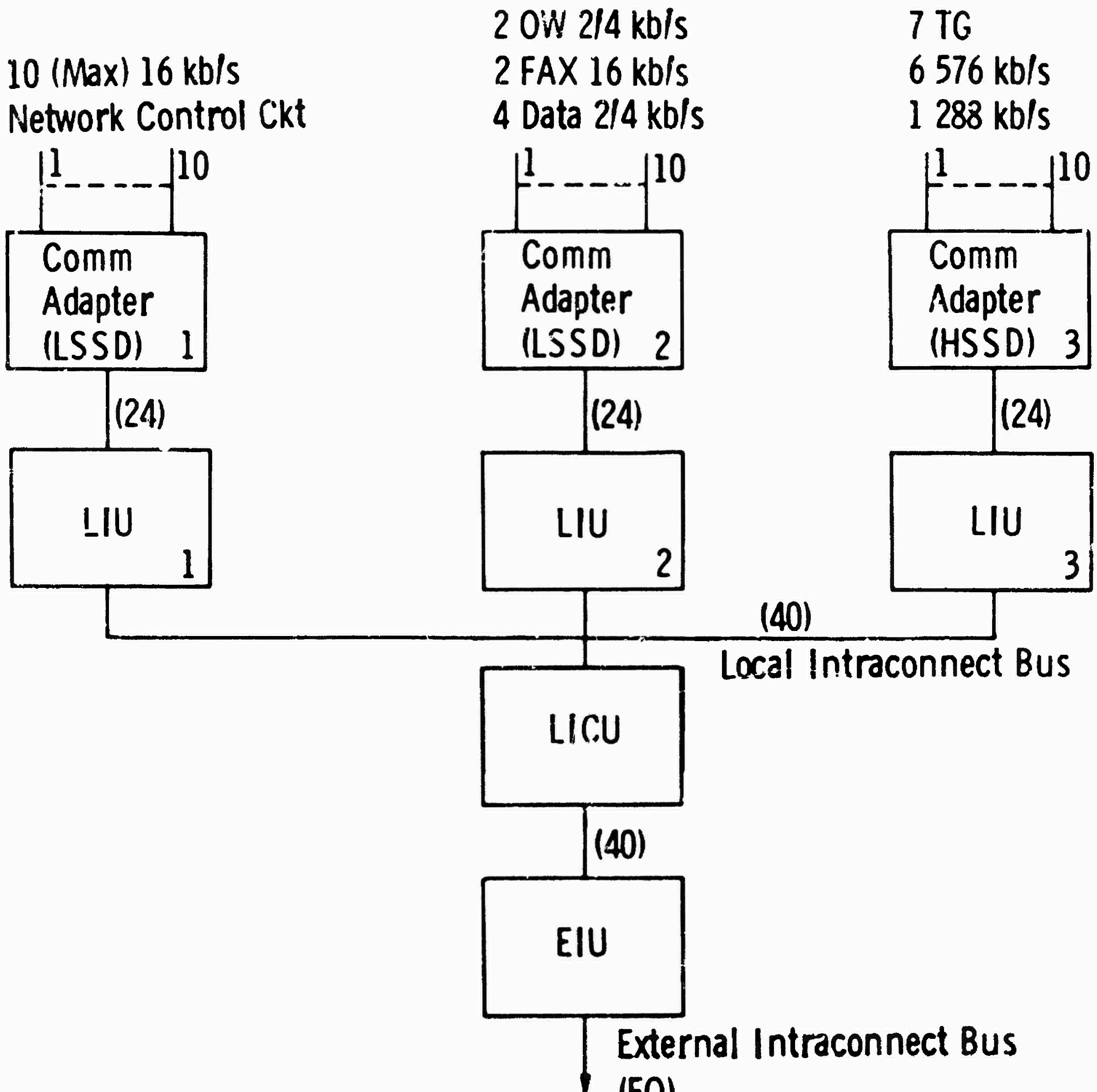


Figure 7-19. TACC/AFCH - radio network controller communications circuits (SCC-4B).

7.1.5 CRC/CRP, SCC-2. Interfaces with the FI at the CRC/CRP center for SCC-2 configurations are shown in Figure 7-20. The FI interface will be implemented with an interface module (IM) attached to the outside of each shelter. The IM contains adapters, LIUs, LICUs and EIUs. This implementation method was described for the TACC in Paragraph 3.5.1.

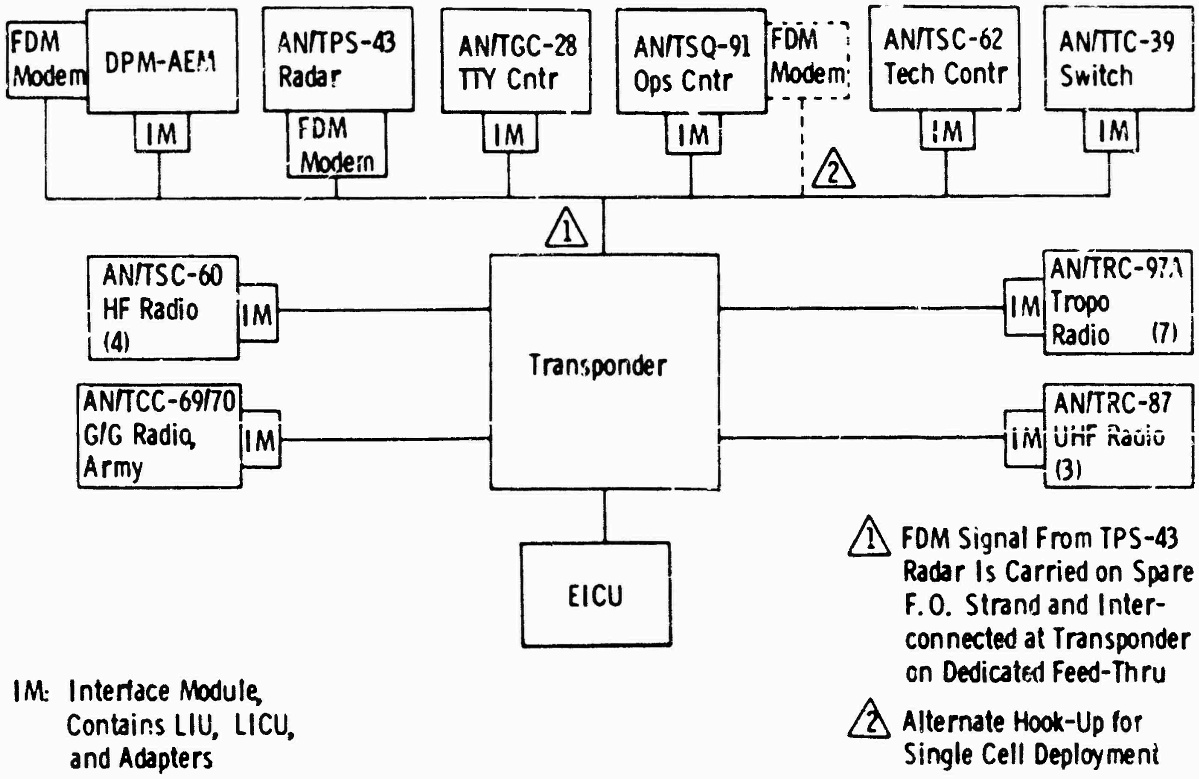


Figure 7-20. CRC/CRP (SCC-2).

7.1.5.1 Operations central shelter, AN/TSQ-91. Interfaces between the operations central shelter and the FI are shown in Figure 7-21. There are 9 radar height signals and 8 radar video signals which inteface with the TPS-43 radar. The radar signals are transmitted from the TPS-43 radar shelter to the operations central over a spare strand of the fiber optics cable. The radar signals do not use the time division multiplex functions of the FI. The 17 radar signals are frequency division multiplexed and transmitted over the bus by FDM modems. When the AEM-DPM units are collocated with the operations central, the FDM modem may be located at either shelter, but when located separately, the FDM modem would be at the AEM-DPM shelter because of its proximity to the radar signal processor.

The FDM modem circuits will interface with the spare FO strand at the EIU.

There are 90 analog telephone circuits interfacing with the FI over 9 AV communication adapters and 15 control lines to the TSC-62 that interface over two CS communication adapters.

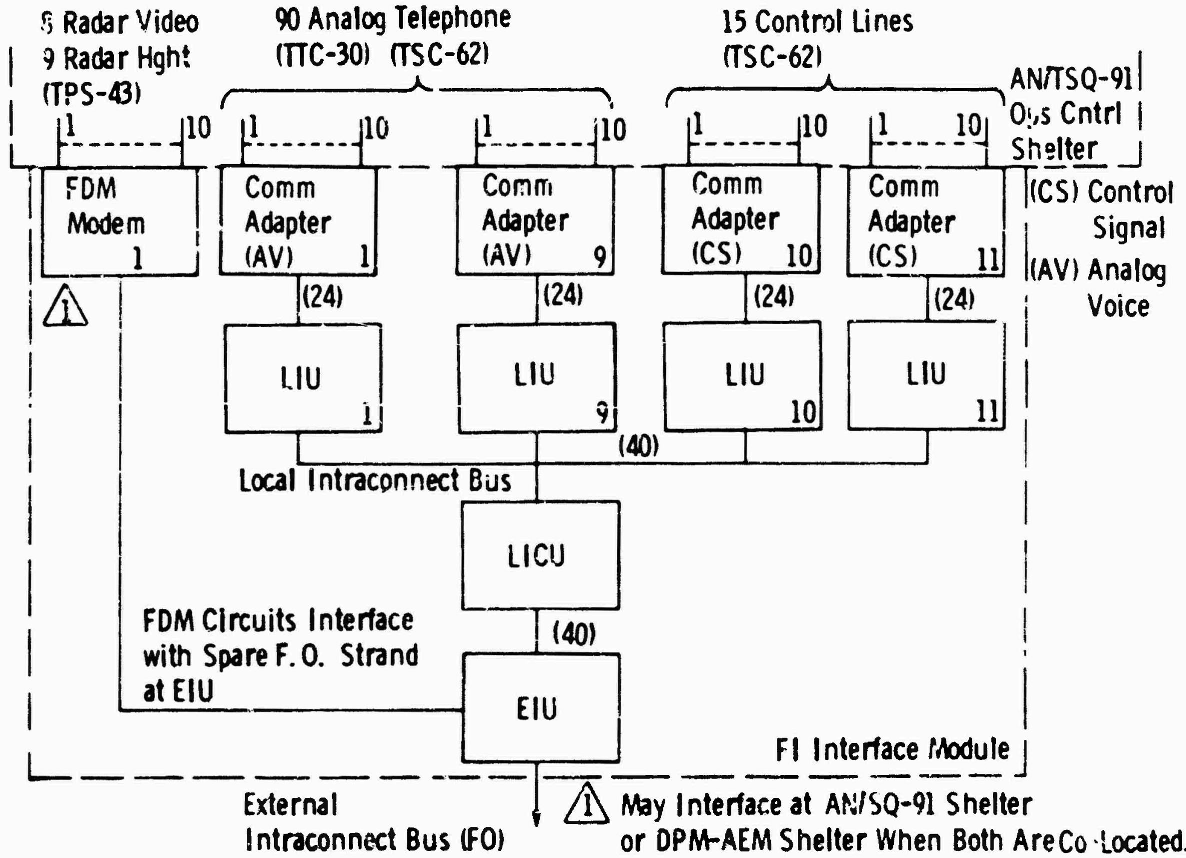


Figure 7-21. CRC/CRP - operations central communications circuits (SCC-1 & 2).

7.1.5.2 AN/TPS-43Radar, SCC-1, -2, -3. The 8 radar video and 9 radar height signals from the TPS-43 radar shelter are transmitted as an FDM multiplex over one strand of the FO cable to the operations central cell and the AEM-DPM. Refer to Figure 7-22.

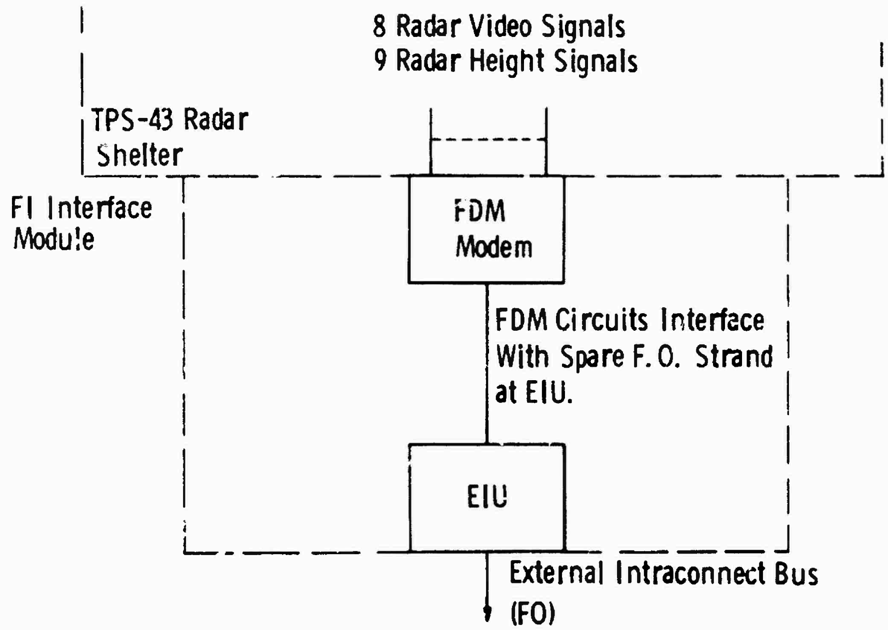
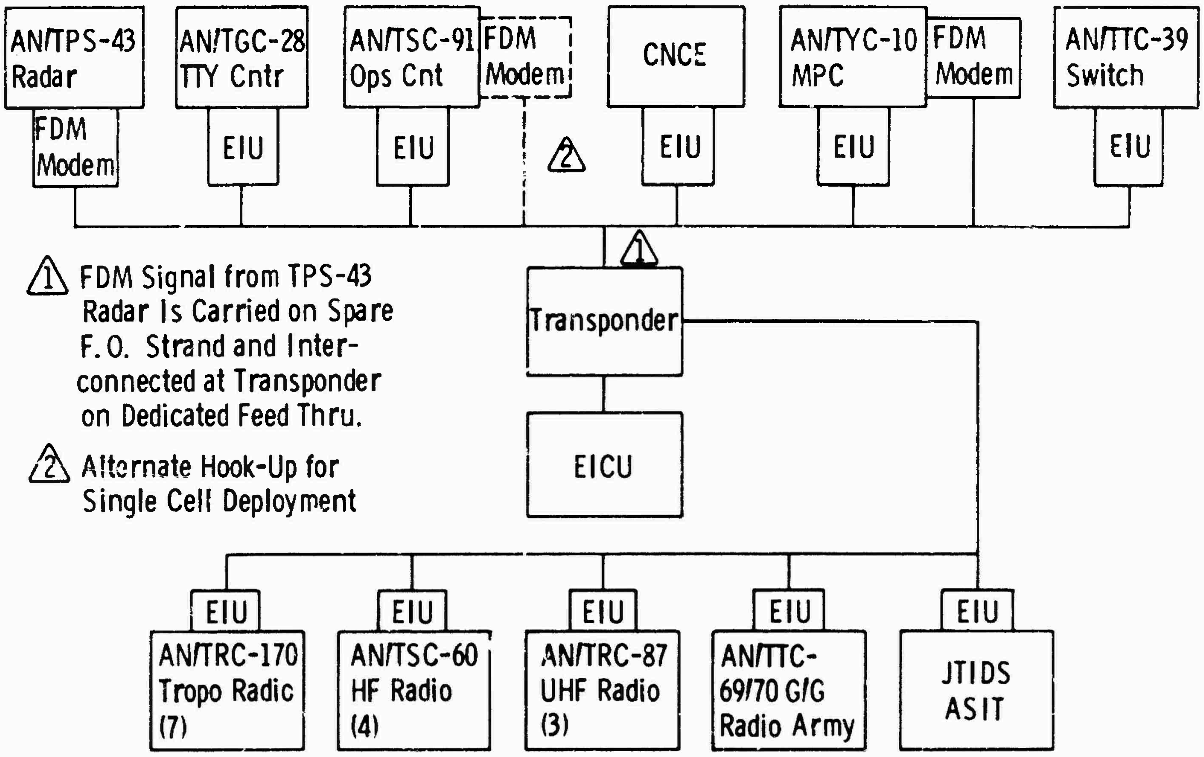


Figure 7-22. CRC/CRP, TPS 43 radar communications circuits (SCC-1, 2, & 3).

7.1.5.3 CRC/CRP, SCC-3. The CRC/CRP is configured identically in SCC-3 with minor traffic changes. In SCC-3, it is anticipated that some shelters can be modified to include FI components internal to the shelters. In those shelters where this is not possible, the IM will be mounted outside the shelter wall (Fig. 7-23).



Note: Shelters which cannot be modified internally will have an interface module (IM) installed outside containing LIU, LICU, adapters, and EIU.

Figure 7-23. CRC (SCC-3).

7.1.5.4 CRC/CRP, SCC-4A. The CRC/CRP interfaces with the FI as shown in Figure 7-24. The main communication differences between SCC-4A and earlier SCCs, other than traffic loads, are that the TPS-43 radar has a digital interface with the OPS central or AEM-DPM shelters, and radar decoys are present. There are other differences in the ADP concepts explained in the ADP section.

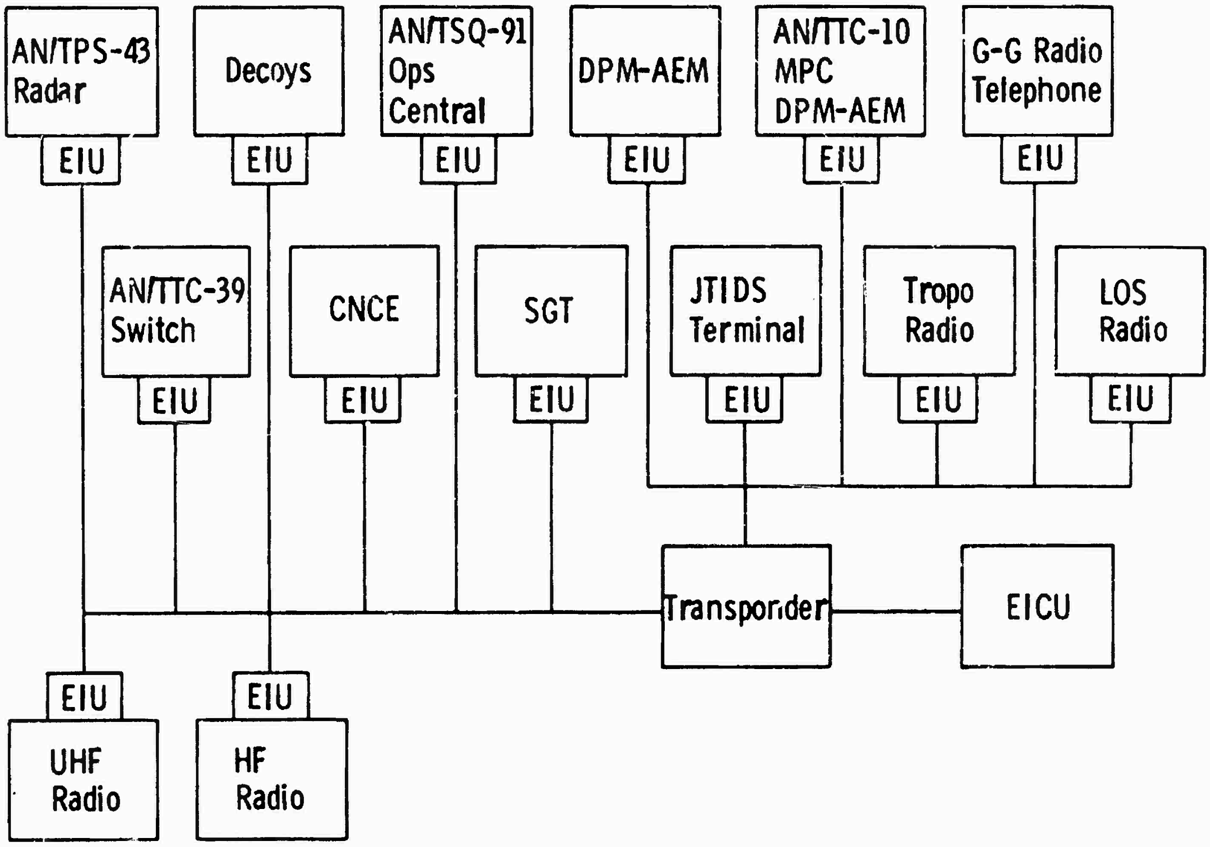


Figure 7-24. CRC/CRP (SCC-4A).

7.1.5.5 Operations central, intrashelter bus for 3 colocated cells, SCC-4A. Figure 7-25 shows the Intrashelter Bus interface with the FI for both communication and ADP devices within the 3 Cell Operations Central. This configuration was chosen in Task 1 for the illustration of the maximum intrashelter bus traffic load expected for all SCCs. Only the communication interfaces are described here.

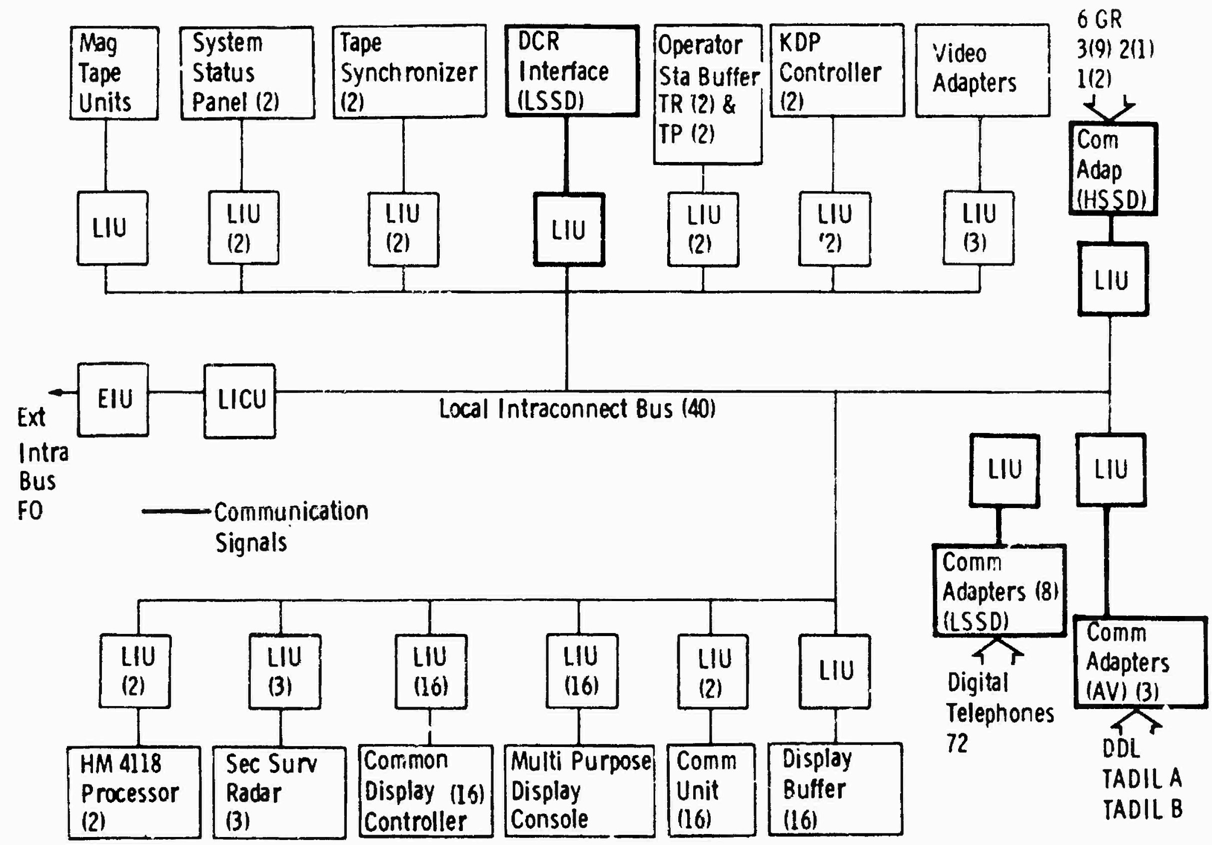


Figure 7-25. CRC/CRP operations central intrashelter bus - 3 collocated cells (SCC-4A).

The Radar interface is a simple 16-kb/s link between the radar shelter which has been modified for digital circuits, i.e., DCR, and the SSRP. There are 6 trunk groups interfacing through HSSD adapters, 12 digital telephones which interface through LSSD adapters, and one AV communication adapter allotted to quasi-analog digital circuits.

7.1.5.6 CRC/CRP, SCC-4B. The system diagram for the CRC/CRP is shown in Figure 7-26 for SCC-4B. The netted radar and netted radio concepts are shown with interfaces to the FI being made at the radar and radio controller functions.

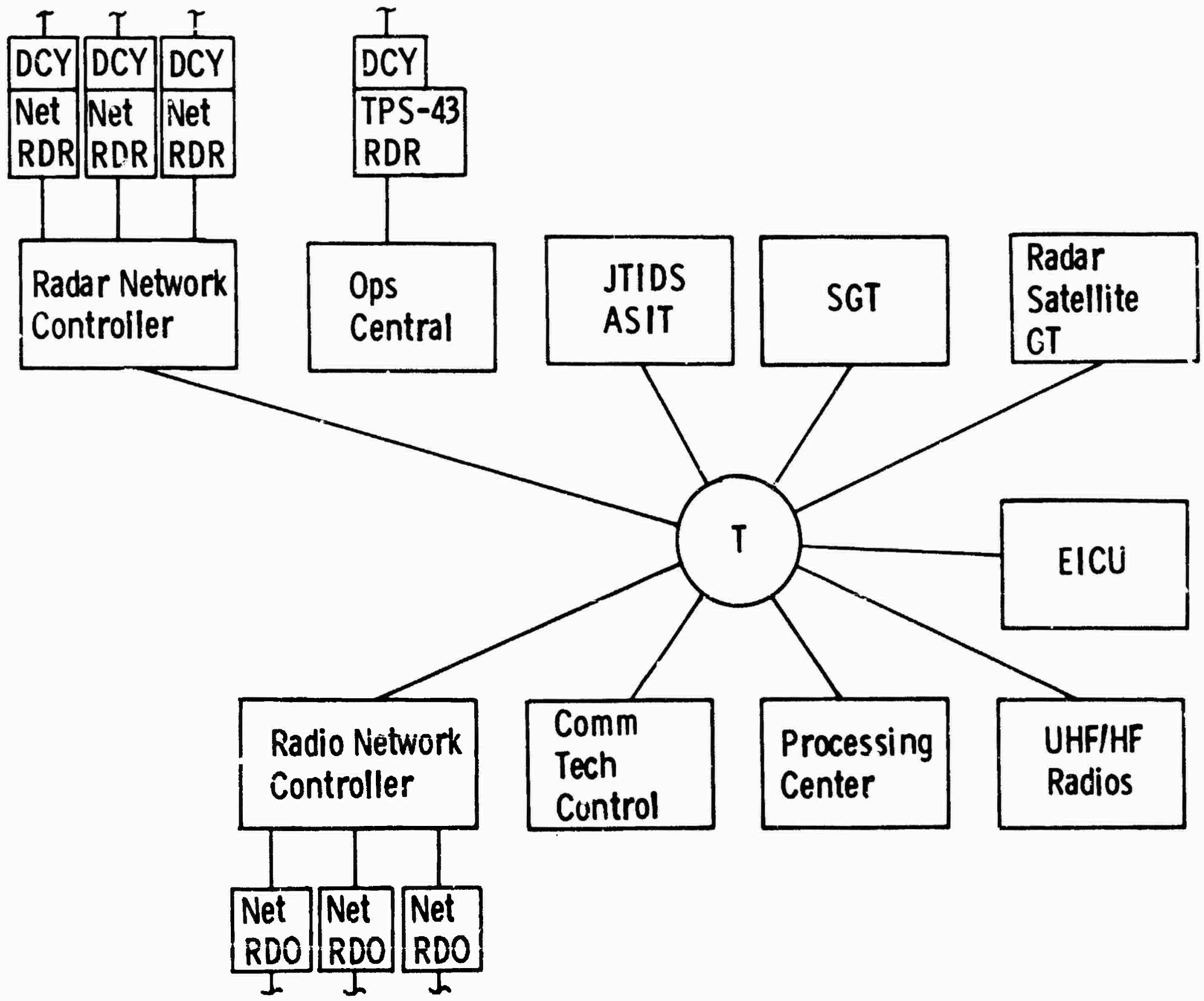


Figure 7-26. CRC/CRP, system diagram showing FI external bus (SCC-4B).

7.1.5.7 TACC, SCC-4B. A composite connectivity drawing of the TACC is shown in Figure 7-27. This drawing shows the intrashelter bus connected to the intershelter bus.

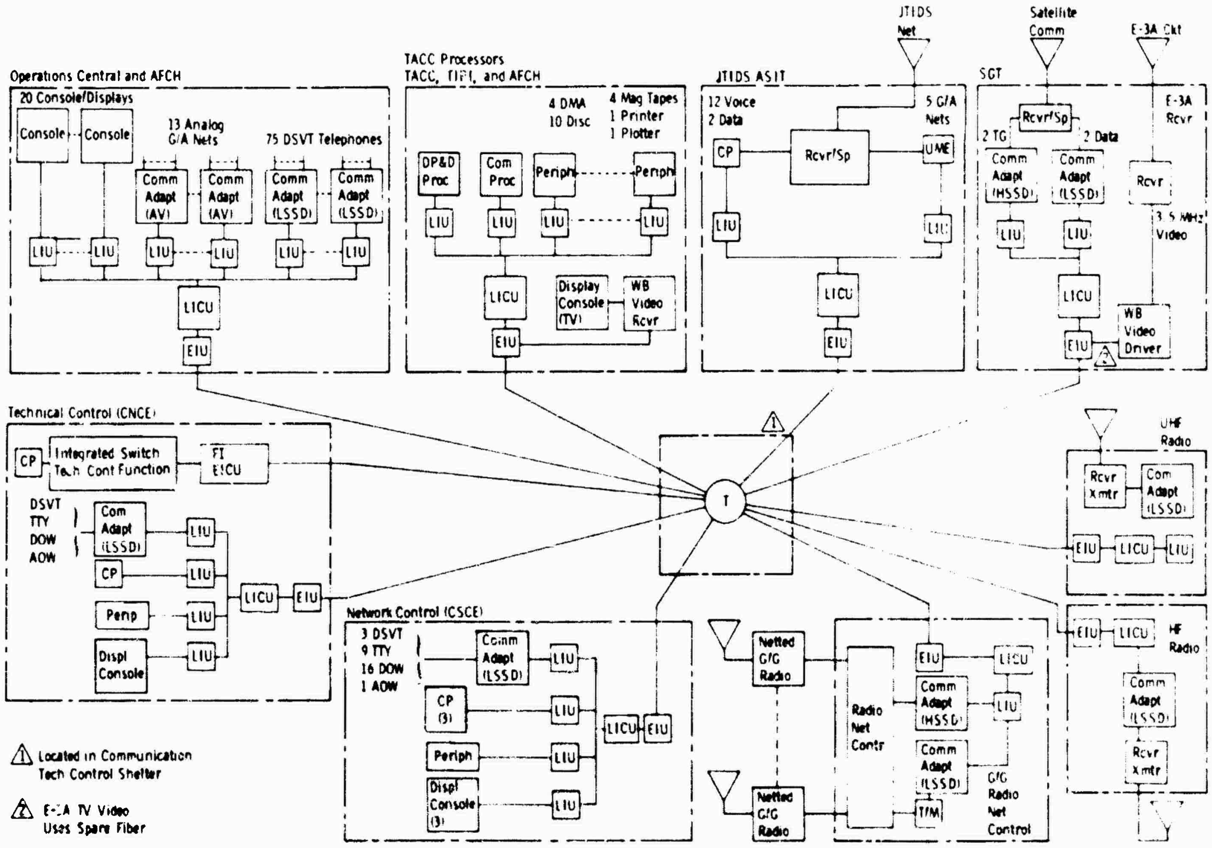


Figure 7-27. TACC center - FI (SCC-4A & B).

7.1.5.8 DASC, SCC-2, SCC-3, SCC-4B. System connectivity drawings for the DASC in SCC-2, SCC-3, SCC-4B are shown in Figures 7-28, -29, and -30.

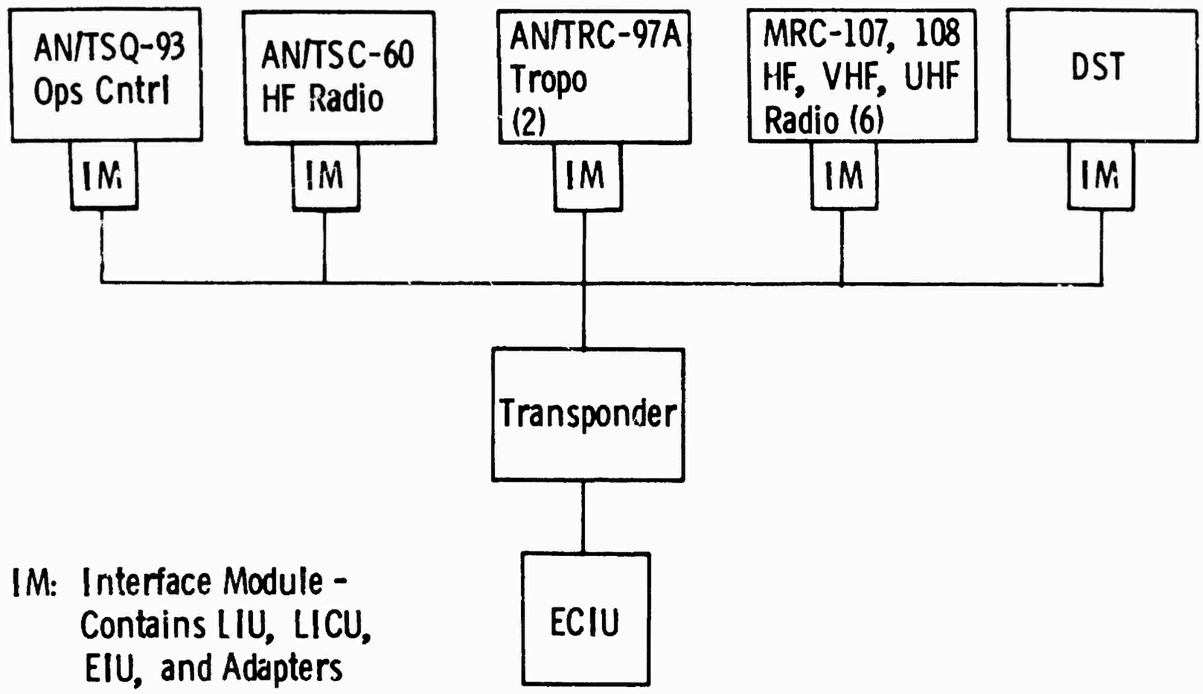


Figure 7-28. DASC (SCC-1).

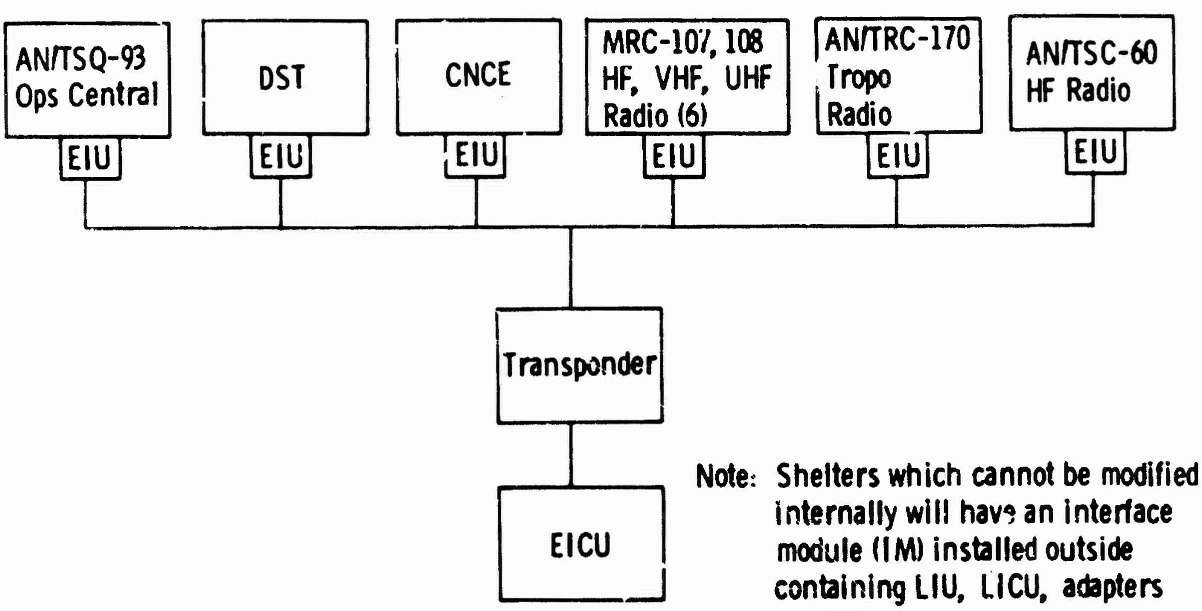


Figure 7-29. DASC (SCC-3).

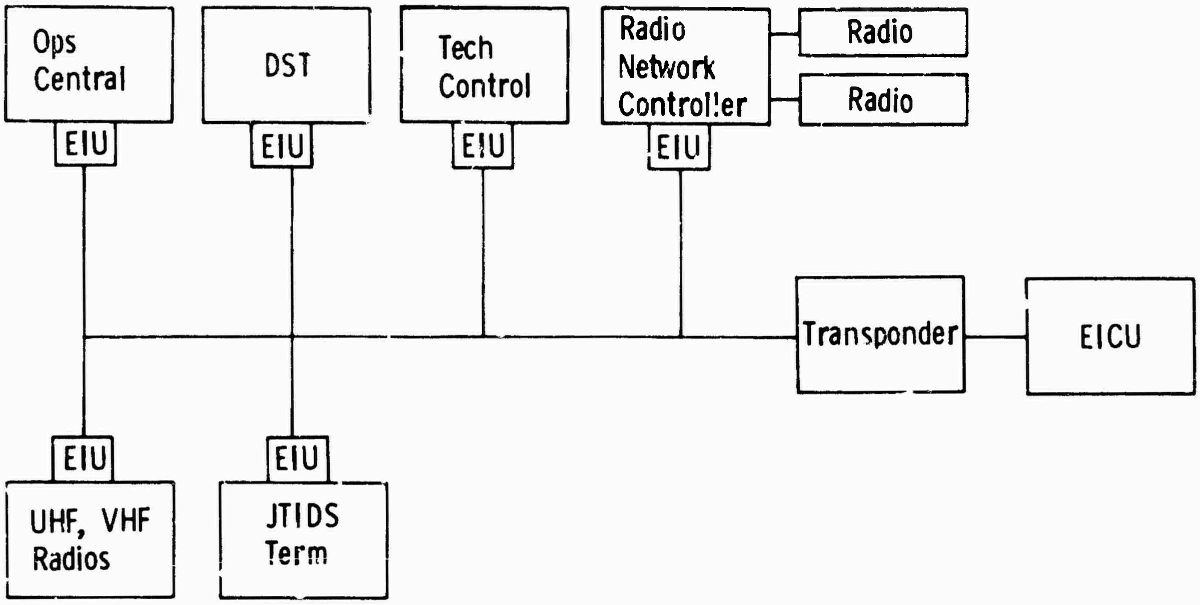


Figure 7-30. DASC (SCC-4B).

7.1.6 FI implementation in low-traffic centers. Some TAC centers do not have the heavy traffic loads carried by the TACC/AFCH, CRC/CRP, and DASC; and consequently do not approach full capability of the FI. The TWAC, ALCC, TUOC, ALCE, FACP, and ASRT occupy less than 3 Mb/s each on the FI. Refer to The Intershelter Traffic Summary Table 2-11. In these minor centers it is not necessary to implement the full capability of the FI. The EI is not used and each center is served by one LI. One shelter contains the LICU and all the LIUs. Outlying shelters are extended from the LI by Shelter Intraconnect Units (SIUs).

The FACP and ASRT are described in a typical implementation of the FI in minor RAF centers. When the FACP and ASRT are collocated, as they generally are, the ASRT uses the communication facilities of the FACP. The two facilities are interconnected by a data link (Figs. 7-31 and 7-32).

There are 13 digital telephones, one teletype, a data adapter, and one-unit level switchboard interconnected directly by the LI in the ops central of the ASRT. This could be a tent serving also as a tech control. Three telephones in the AN/TPB-1 Radar Bomb Diverting Set are interconnected to the LI by SIUs. The SIUs use fiber optics for intershelter transmission. The TACAN Radar, I-Band Radar, and TV video are frequency division multiplexed and transmitted by a fiber optics cable to the AN/TPB-1 Radar Bomb Directing Set. The ASRT LI should require approximately 800 kb/s for all traffic.

The FACP LI is located in the AN/TSC-53 tech control and communication set with 13 outlying telephones in the radar shelter and AN/TSQ-61 ops central. One 16-channel digital link connects the FACP to other centers via the AN/TRC-170 tropo radio. The AN/TPS-43 radar signals are transmitted to the AN/TSQ-61 operations central as an FDM multiplex over a fiber optics cable. The FACP LI also carries approximately 800 kb/s traffic.

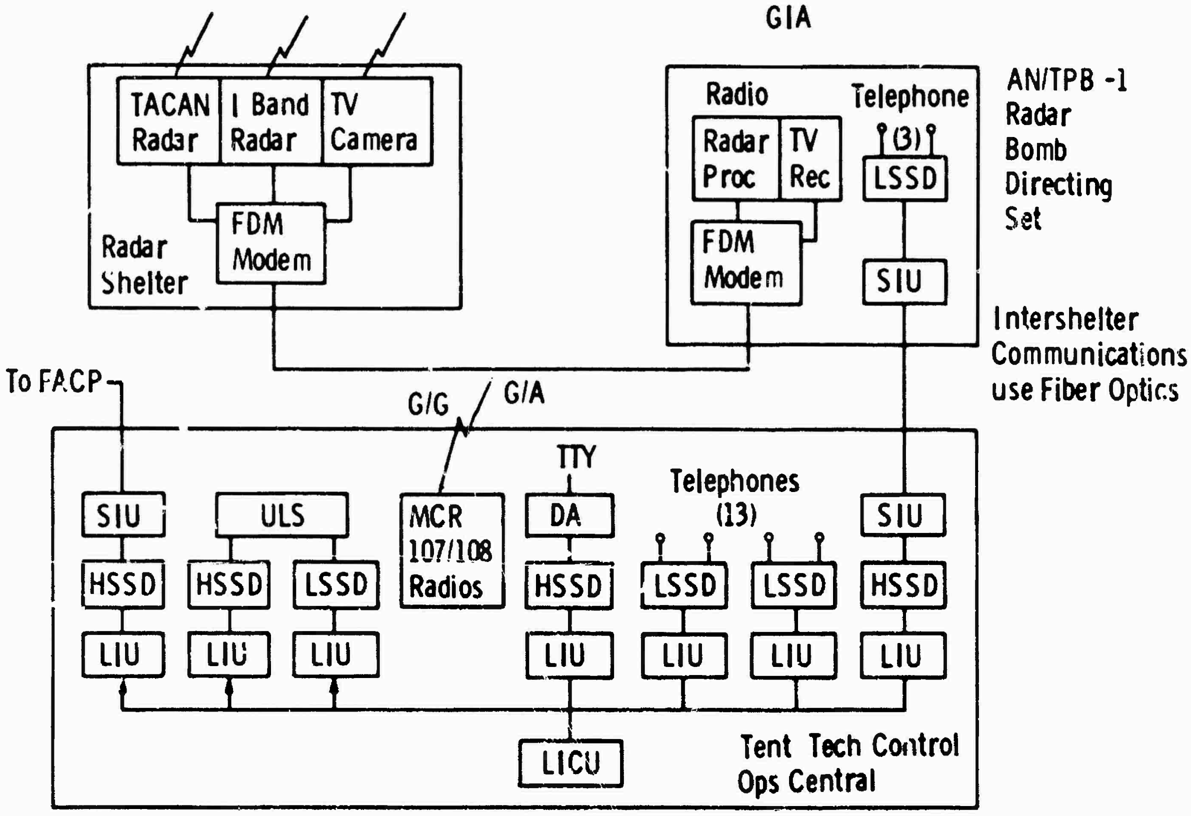


Figure 7-31. ASRT, SCC-3 collocated with FACP.

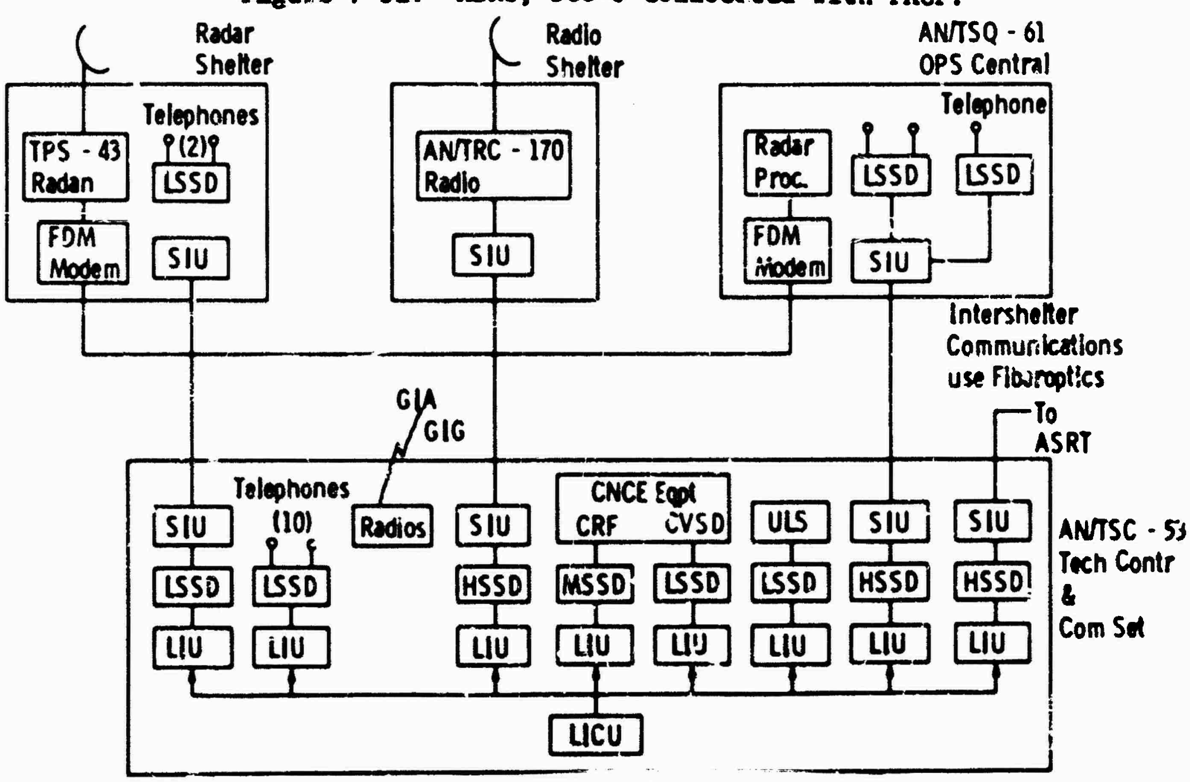


Figure 7-32. FACP, SCC3 collocated with ASRT.

In implementing these centers with SIUs, some consolidation of functions may become apparent and be developed as part of the SIU. For instance, it may be feasible to include the functions of High-Speed Serial Data adapters (HSSDs) and Low-Speed Serial Data adapters (LSSDs) into the SIUs and interface directly with LIUs.

The LICUs in the ASRT and FACP operate autonomously. In the configurations shown, the EI is not necessary.

7.2 FI implementation of ADP functions in a CRC.

7.2.1 Introduction. The 485L configuration of TACC automation equipment for SCC-2 is shown in Figure 7-33. The TACC provides centralized control of all Air Forces available to the Air Force Component Commander. Two functional divisions are identified: Current Plans and Current Operations. Current Plans prepare orders for daily air operations, while Current Operations supervise execution of these air operations. The functions and operations of the TACC are more fully described in MITRE document MTR-3299, Vol. 1.

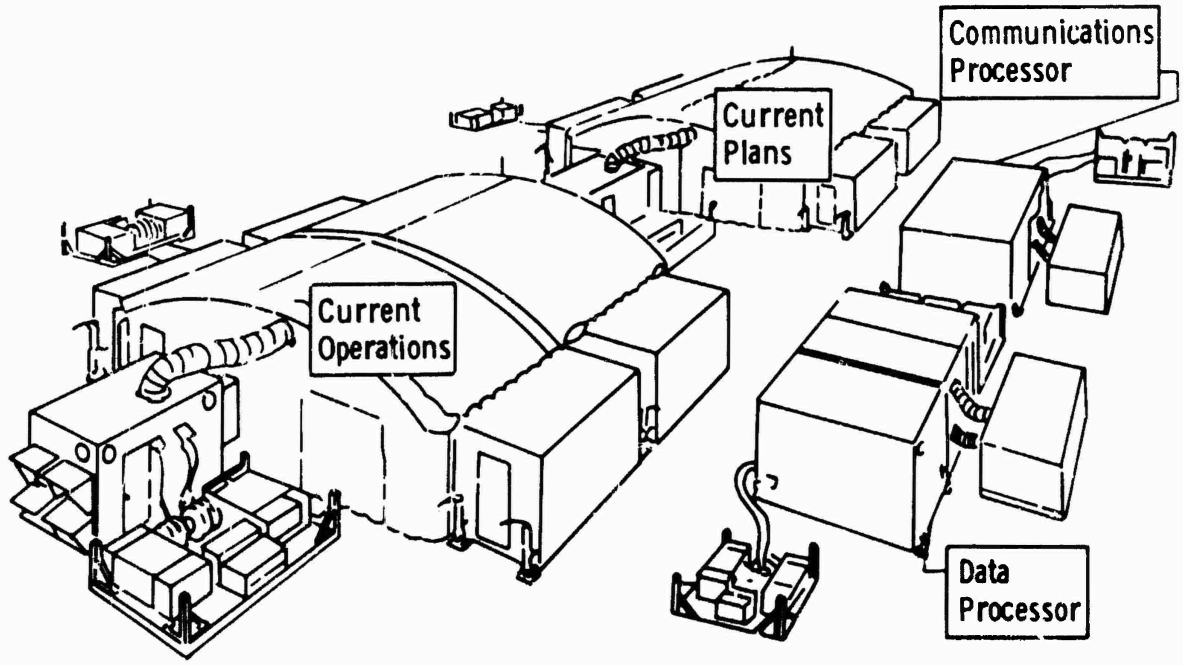


Figure 7-33. AN/TSQ-92(V) TACC with automated equipment shelters.

This configuration can be implemented with the FI and representative ADP equipment as described herein and shown in Figure 7-34. Each shelter would occupy a separate arm from the FI transponder with the EICU and FI Manager residing in one of the shelters. This illustration is not a proposed replacement to the present system, but serves as an aid in explaining the operation of the FI and demonstrates the feasibility of its implementation within a TACC. The represented equipment can be found in the list of ADP equipment contained in the Task II Final Report.

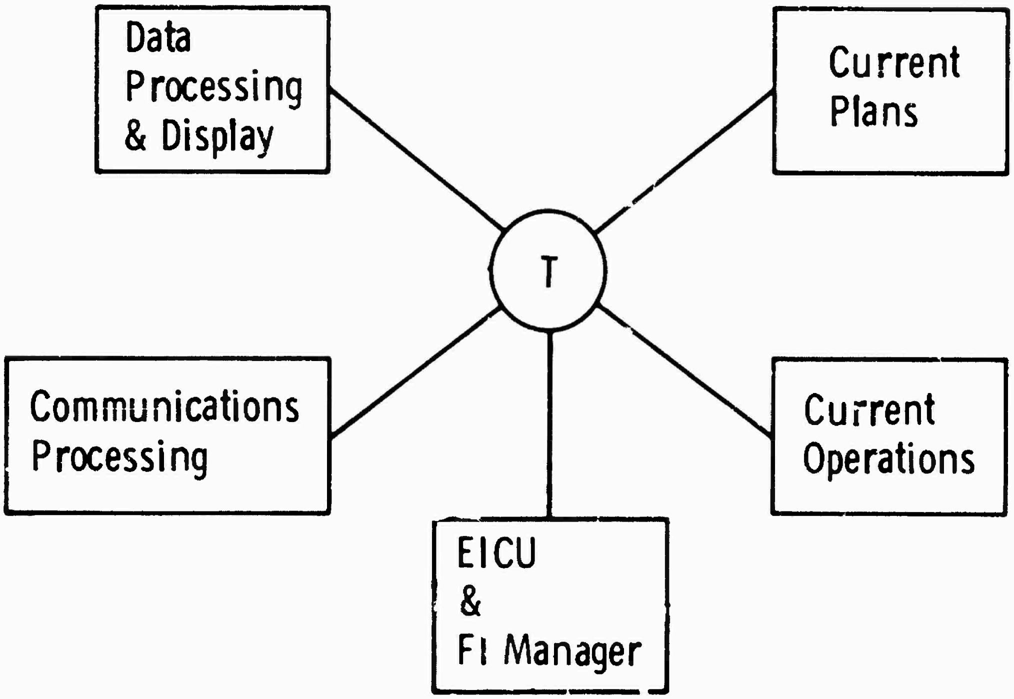


Figure 7-34. Implementation of 485L TACC (SCC-2).

7.2.2 Data processor.

7.2.2.1 ANTSQ-92 (V)data processing equipment. Figure 7-35 shows the SCC-2 equipment. Dual AN/UYK-7 processors are used with one in a backup mode for the other. The capability also exists for the two CPUs to operate in a load-sharing mode. The CPU core memory has a storage capacity of 96k 32-bit words. The Input/Output Controllers (IOC) are programmable units for control of data transfers between core memory and the Input/Output Adapters (IOA). An IOA can multiplex 16 I/O channels to the data lines from an IOC.

The function of an Error Detection Unit (EDU) is to generate a parity bit for data from the IOA and check parity on data to the IOA. The Peripheral Controller Unit (PCU) is a microprogrammable processor providing the data transfer interface between the processors and mass storage. The Line Driver Unit (LDU) provides the computer with the capability of interfacing to equipment 1000ft away.

Primary mass storage consists of Singer Librascope disks and provides storage capacity of 56M/b. The secondary mass storage consists of Univac 1840 magnetic tape transports.

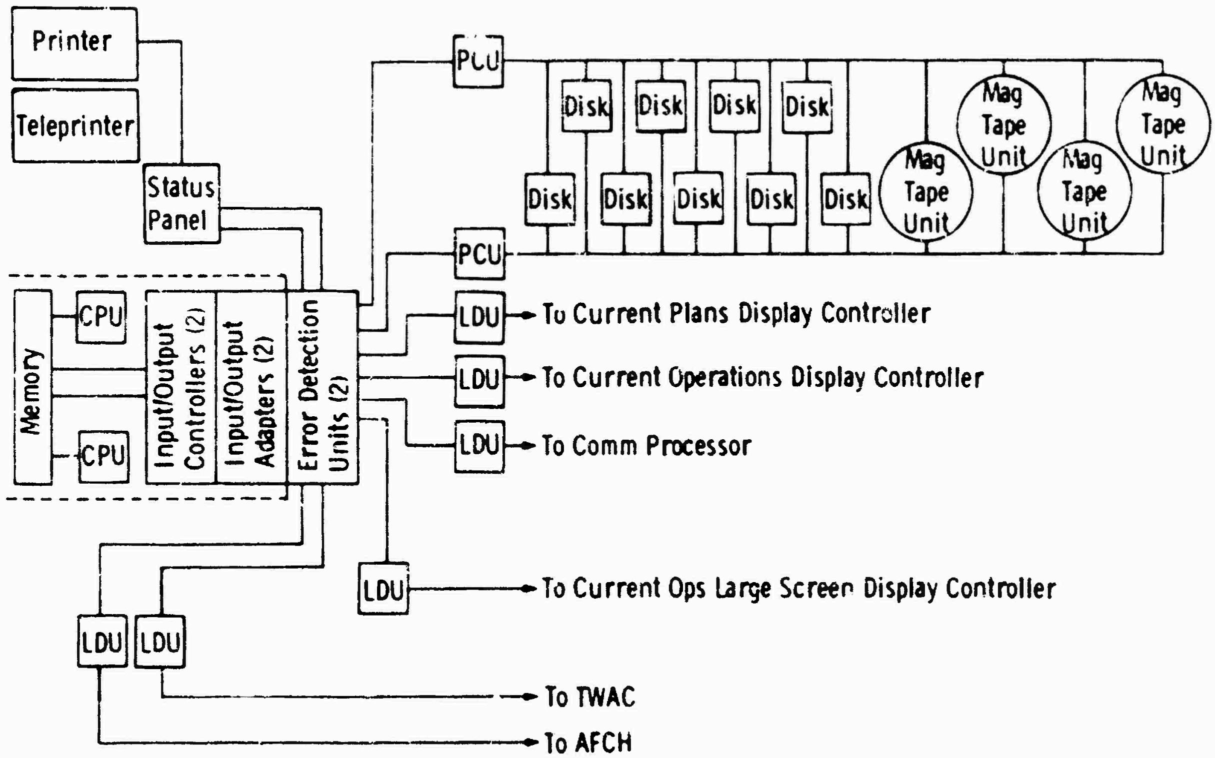


Figure 7-35. AN/TSQ-92(V) data processing equipment (SCC-2).

7.2.2.2 FI implemented data processing equipment. The FI implemented data processor (Figure 7-36) could contain a dual-processor configuration built around DEC's PDP-10, rather than the AN/UYK-7. Using strategically-placed bus switching hardware, one processor can take over the other's role, including control of peripheral devices. If required, the CPUs can also share the data processing load. Both processors could also be independently connected to the FI through individual LIUs. This would allow redundant connections to the FI as well as the capability to operate in load sharing, backup, or stand-alone modes.

Data transfer control and error checking is contained within the LIU and SAU rather than an IOC and EDU, while the FI concept itself eliminates the need for an IOA. Transmission between shelters occurs over fiber optic cables, which do not require LDUs.

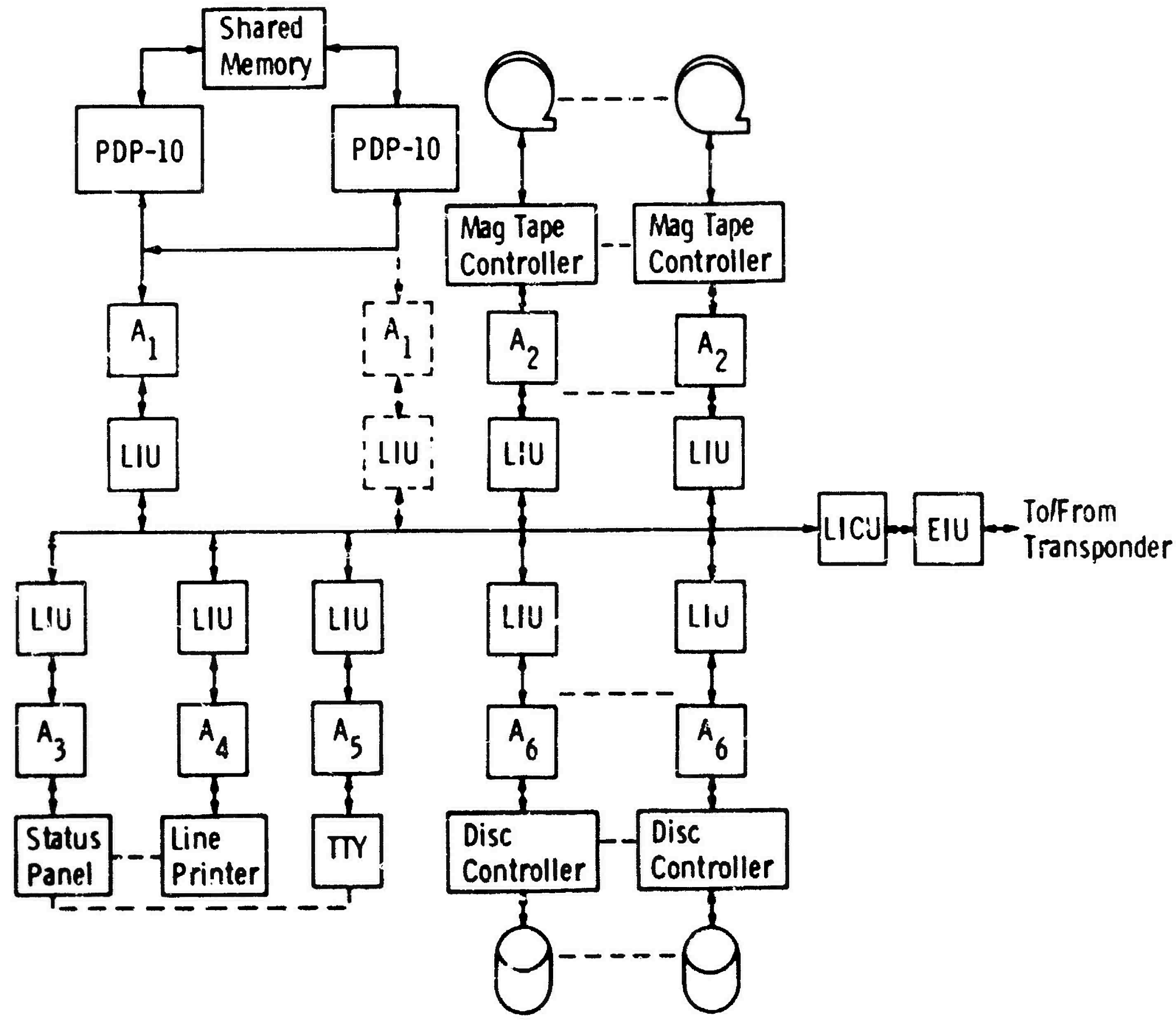


Figure 7-36. FI implemented data processing equipment.

The necessary interface of the PDP-10 to the LIU can be provided by a microprocessor-controlled module (Fig. 7-37). The programmable peripheral interfaces (PPI) are software initialized by the CPU in sequence via the Mux/Demux. Each PPI is programmed to pass data in a bidirectional mode. The 36-bit data to and from the PDP-10 is transferred from and to the data memory in 18-bit words. Latches are required to transform control pulses from the PDP-10 to binary levels for mapping of these signals into data if necessary. Voltage level conversion is also required between the TTL levels of the PPIs and the -3V levels of the PDP-10. Timing for the transfer of data to/from the PDP-10 is shown in Figure 7-38.

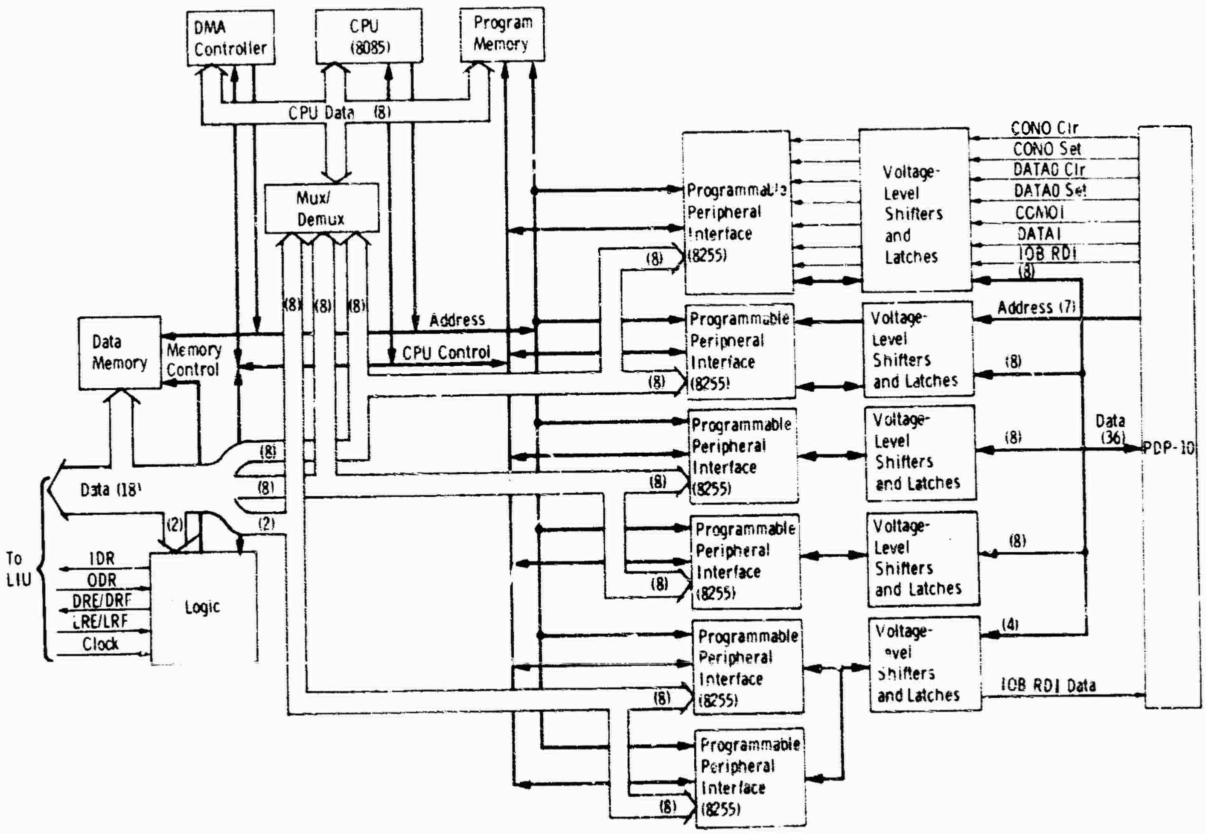


Figure 7-37. PDP-10 interface.

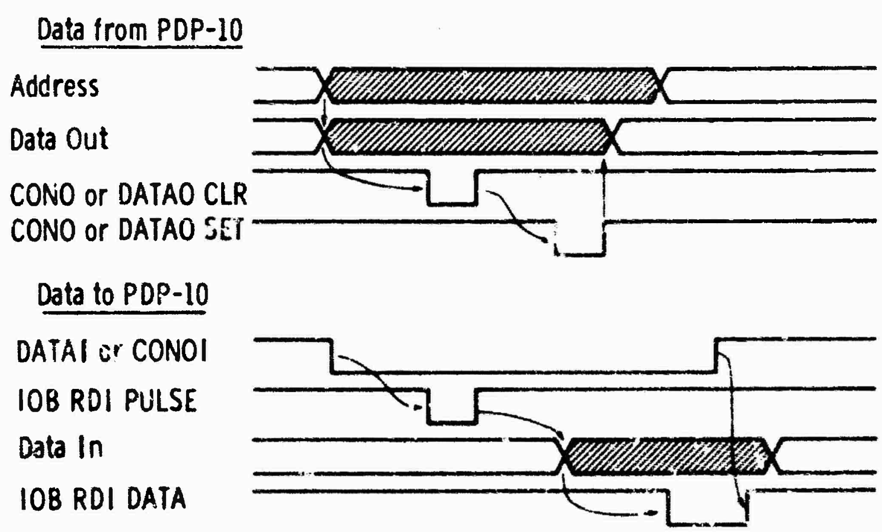


Figure 7-38. PDP-10 I/O bus timing.

Errors can be recorded by DEC's TOPS-10 Monitor operating system. Transmission errors are detected using block-oriented techniques including longitudinal data checks. TOPS-10 also provides diagnostics to facilitate on-line maintenance of a peripheral device concurrent with user-mode operation.

DEC's RHS04 disk drive could be a replacement for the currently designated Singer Librascope L107MA, providing a subsystem storage capacity of 9.2M/b per disk compared to 6.3M/b for the Librascope. However, for the purpose of illustrating a different adapter (the RHS04 would require an adapter similar to that used by the PDP-10) and the flexibility of the FI concept, the primary mass storage will consist of the existing equipment, i.e., 9 Librascope L107MA disk units. The required interface between the disk controller and the LIU is provided by an adapter (Fig. 7-39). The interface to the disc controller conforms to MIL-STD-1397, Type B. The hardware is very similar to that in the PDP-10 adapter. The 8085 CPU performs the same functions of initialization and message header management. Voltage level conversion is needed to match TTL levels to the -3V levels of the disk controller. The real difference between this adapter and the previously described PDP-10 adapter lies in the software which sets up the mode of data transfer in the PPIs. For timing and handshaking considerations, see Figure 7-40.

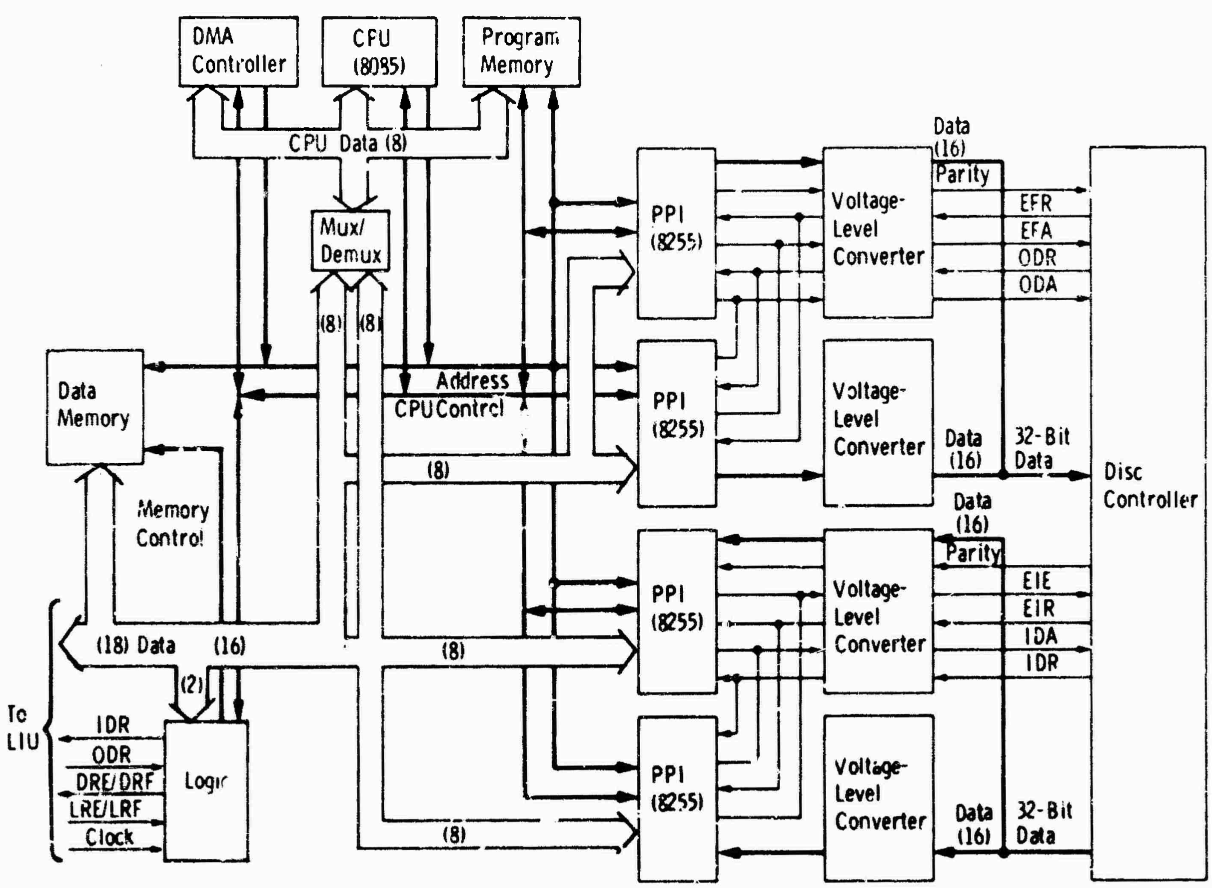


Figure 7-39. Disc controller interface.

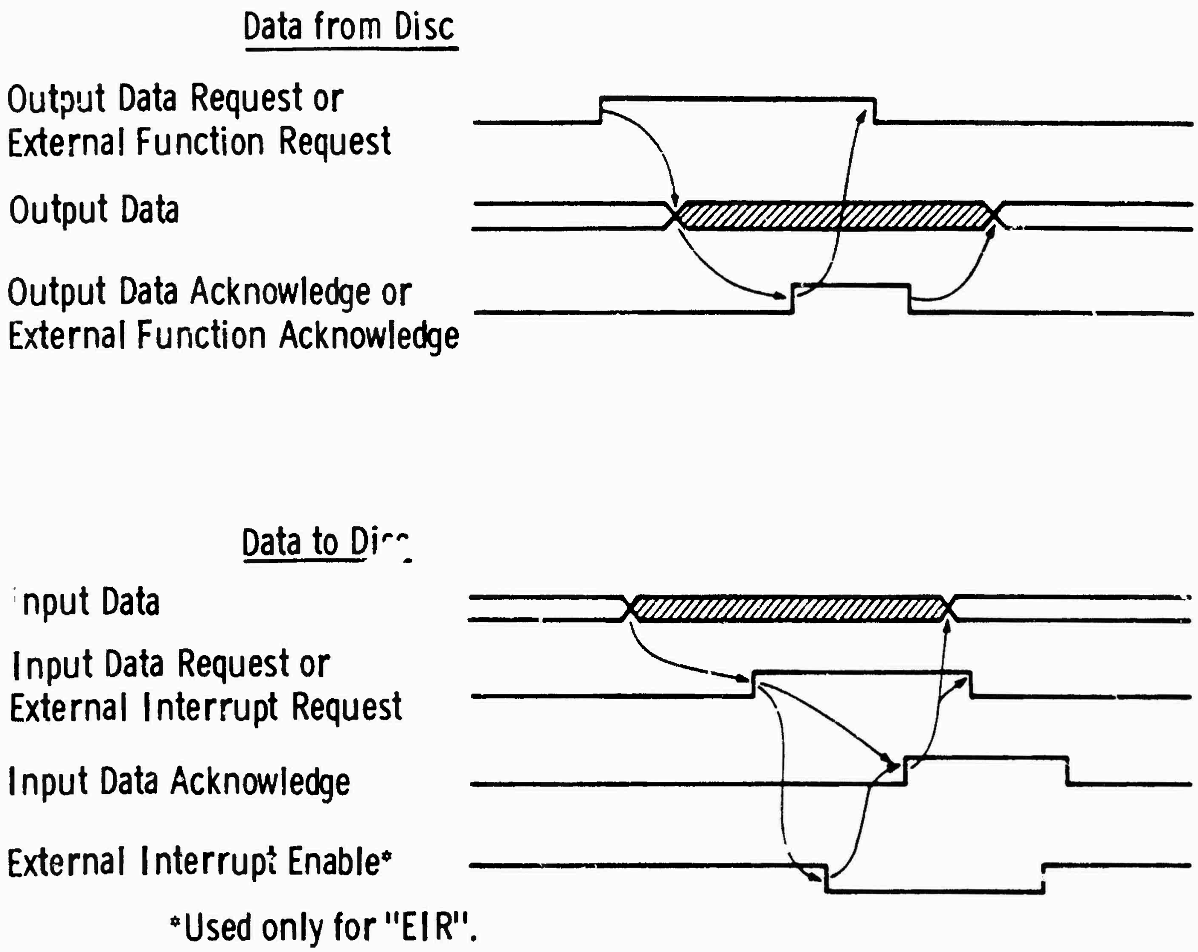


Figure 7-40. Disc controller timing.

Interface to the secondary mass storage equipment consisting of four Univac 1840 Magnetic Tape Transports can be accomplished via a similar adapter with any required adjustments being made in the software of the LIU. The data path would decrease to 16 bits plus parity in both directions.

The line printer and teletype can interface directly to the status panel or via the FI. Both peripherals can connect to the FI through a serial communications SAU as described in Section 6.4.7. The status panel can interface through a SAU similar to that used for the mag tape transports.

7.2.3 Current plans and operations.

7.2.3.1 ANTSQ-92(V) current plans and operations. The SCC-2 equipments are shown in Figures 7-41 and -42. A General Dynamics display controller provides the interface between the display stations and the processor. The functions of this display controller are to:

a. Multiplex data between the data processor and display stations;

b. Check parity on data to and generate parity on data from a display station;

c. Generate status words to the computer on the operational condition of the display stations; and

d. Act as a backup to the other display controller.

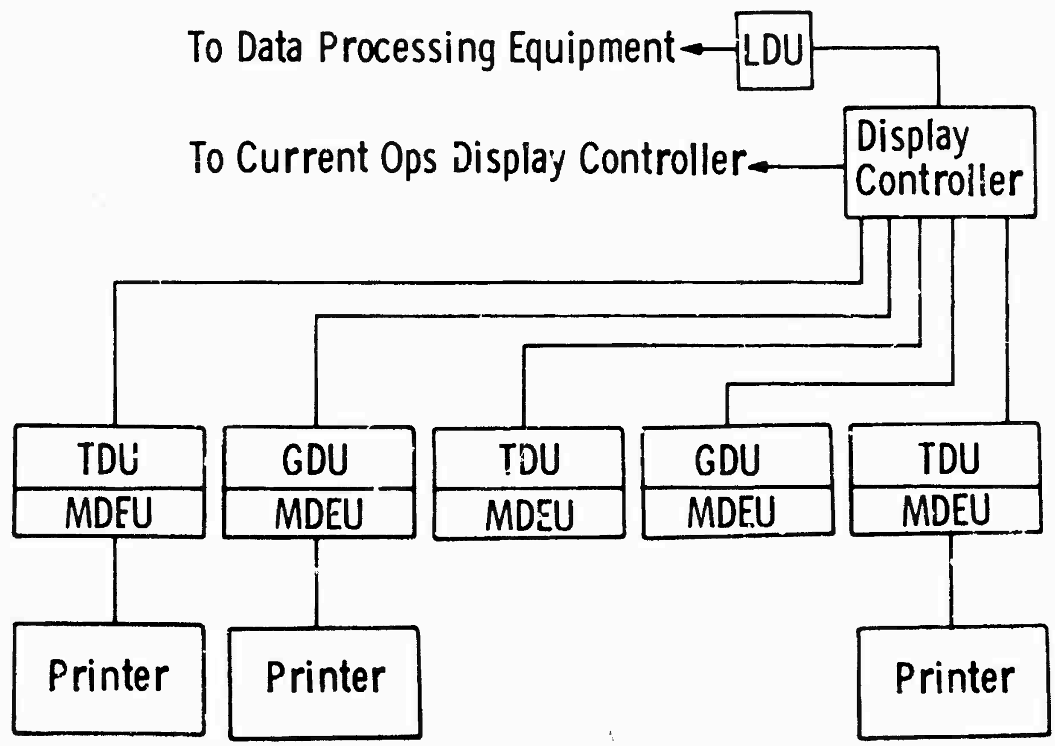


Figure 7-41. Current plans (SCC-2).

A tabular display station consists of a tabular display unit (TDU), a manual data entry unit (MDEU), and a hard-copy line printer. A graphic display station is similar but contains a graphic display unit (GDU) in lieu of a TDU.

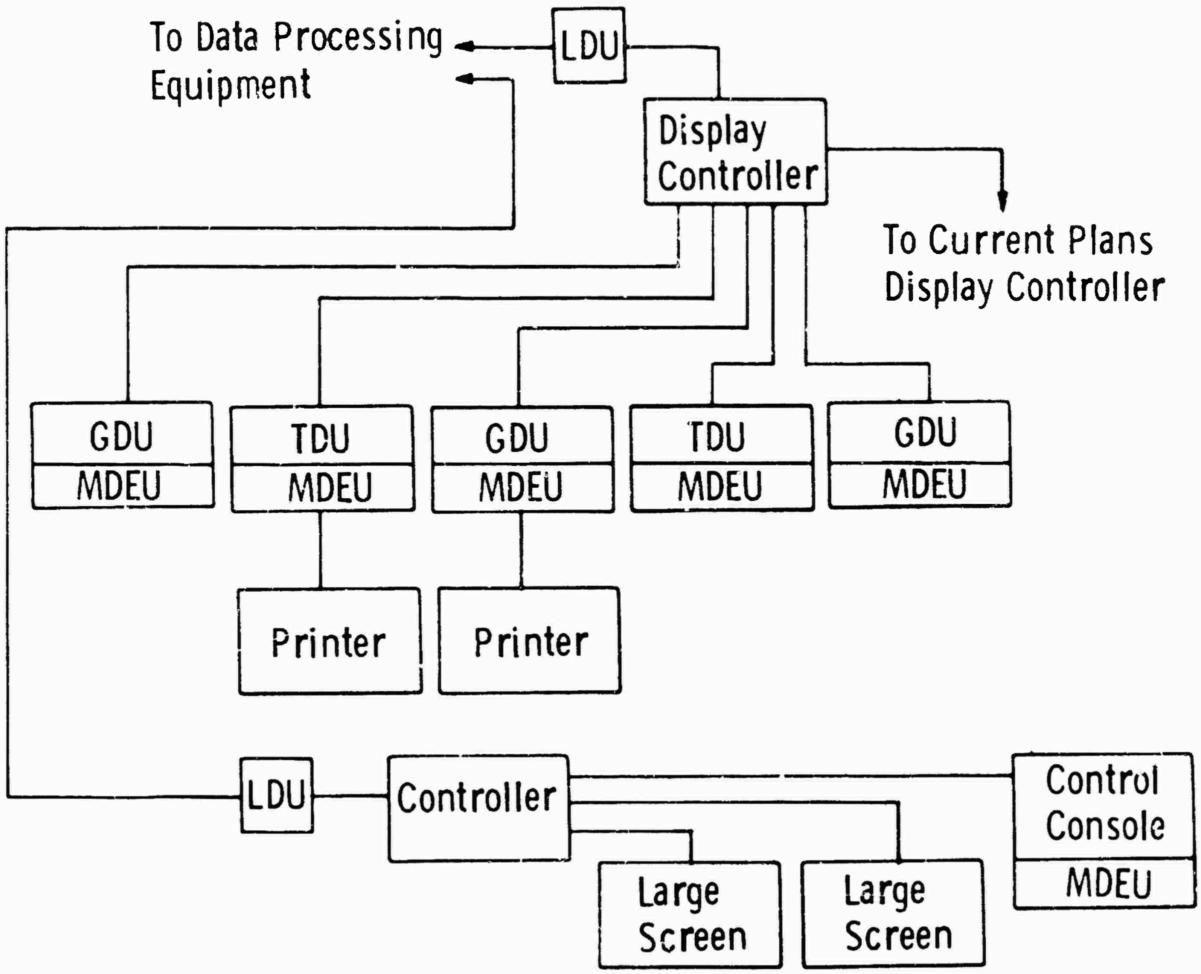
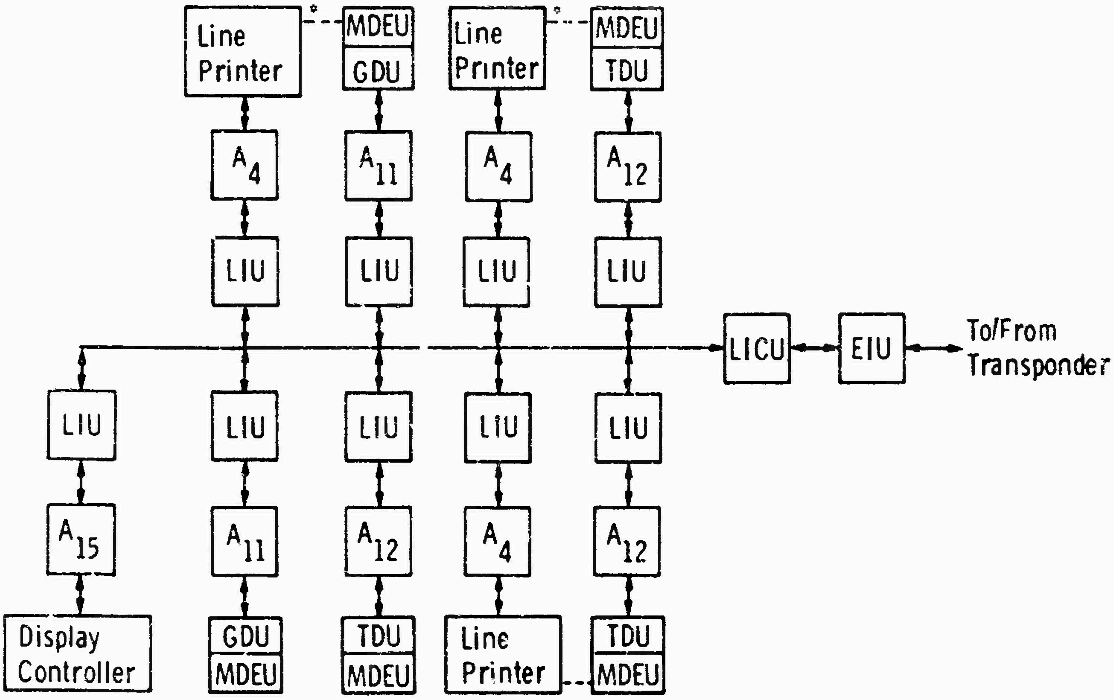


Figure 7-42. Current operations (SCC-2).

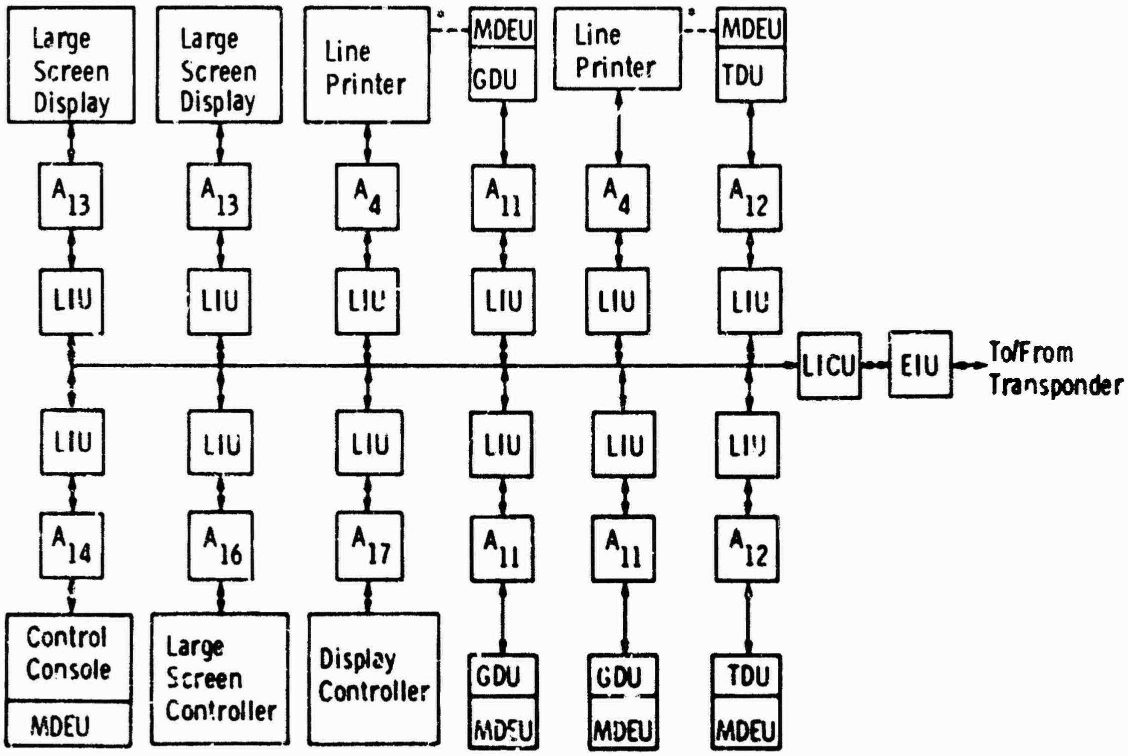
The group display for Current Operations consists of a control console, a large-screen situation display, and a large-screen status display.

7.2.3.2 FI implemented current plans and operations. Current Plans and Operations shelters could be implemented on the FI as shown in Figures 7-43 and -44. The same display controller in both shelters can interface to the FI through an LIU and adapter with the display stations connected to the FI via the display controller. An alternate method is to connect each display unit and keyboard directly to the FI through separate adapters and LIUs as illustrated. This approach can apply to the large-screen controller as well. This offers more flexibility in adding or deleting a variety of display units to the shelters. The display controllers are included in the implementation in order to minimize the impact on software if they were eliminated altogether. The possibility of removing the controllers does exist by checking and generating parity in the LIUS, generating status words in the adapters, and replacing the multiplexing function by proper display applications software (CPU-to-terminal drivers). However, it may prove to be much more cost-effective to let the controllers continue to provide these functions.



*Printer may be directly connected to display or via the FI.

Figure 7-43. FI implemented current plans.



*Printer may be directly connected to display or via the FI.

Figure 7-44. FI implemented current operations.

The line printers can interface via the MDEUs or directly to the FI by way of a serial comm adapter as described in Section 6.4.7.

7.2.4 Communications processor.

7.2.4.1 ANTSQ-92(V) communications processor (SCC-2). The SCC-2 configuration of the communications processor in Figure 7-45 shows redundant CPUs consisting of two CDC Microprogrammable Processors (MPP) designed to emulate CDC-1700s. Upon failure of one processor, the other can handle the full communications processing load. This configuration also provides for bypassing these processors by changing the cables so the data processor can acquire control.

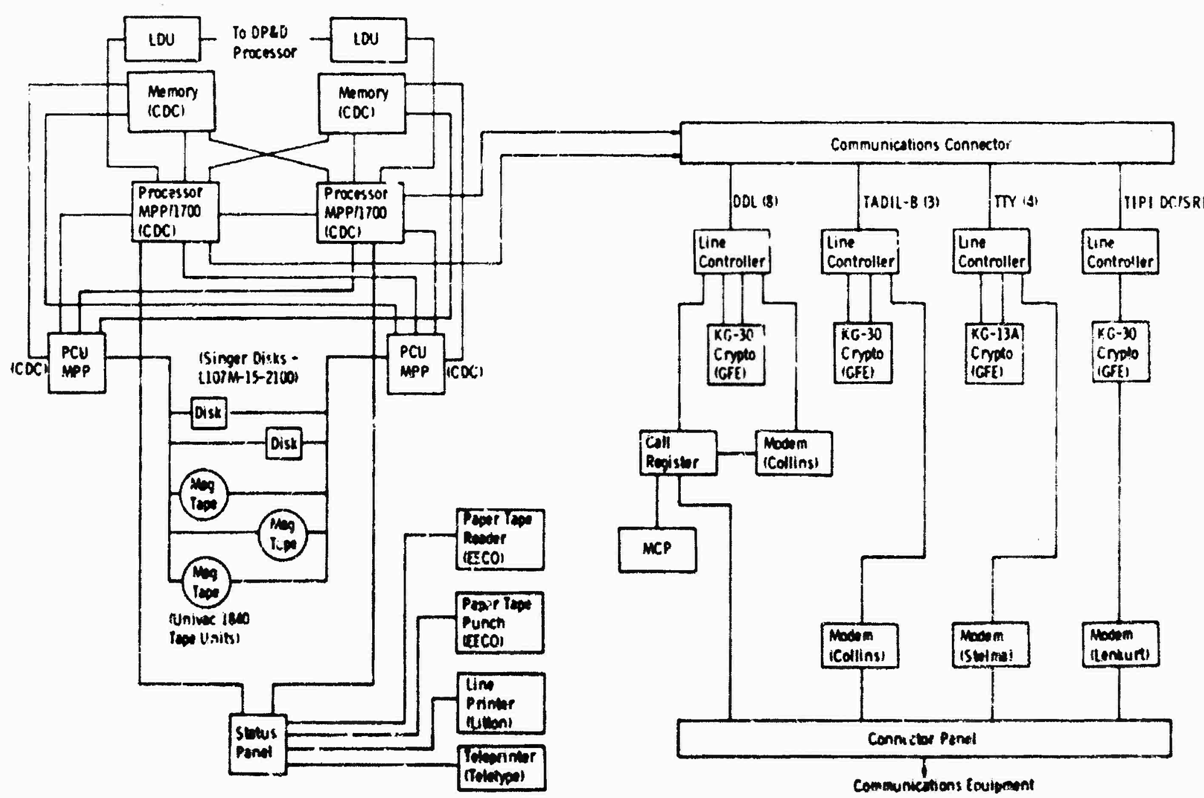


Figure 7-45. Communications processor equipment.

The Peripheral Controller Unit (PCU) is a version of the CDC MPP and controls the transfer of data between the computers and storage. The PCUs can be programmed to match I/O characteristics of the different equipment types.

7.2.4.2 FI implemented communications processor. The implementation of the communications processor on the FI could be as shown in Figure 7-46. The CDC MPPs can be replaced by two PDP 11/70s communicating through a DA11-B Interprocessor Link (a standard Digital Equipment Corporation product) that passes control information and interrupt requests between the two computer interfaces. This provides a means by which one processor can take over the full communications processing load upon detection of a failure in the other processor. The PDP 11/70 processors could also connect to the FI through individual adapters and LIUs to provide redundant paths as well as redundant processors, and capability to operate in a load-sharing mode. The PDP 11/70 also gives more processing power for future growth possibilities.

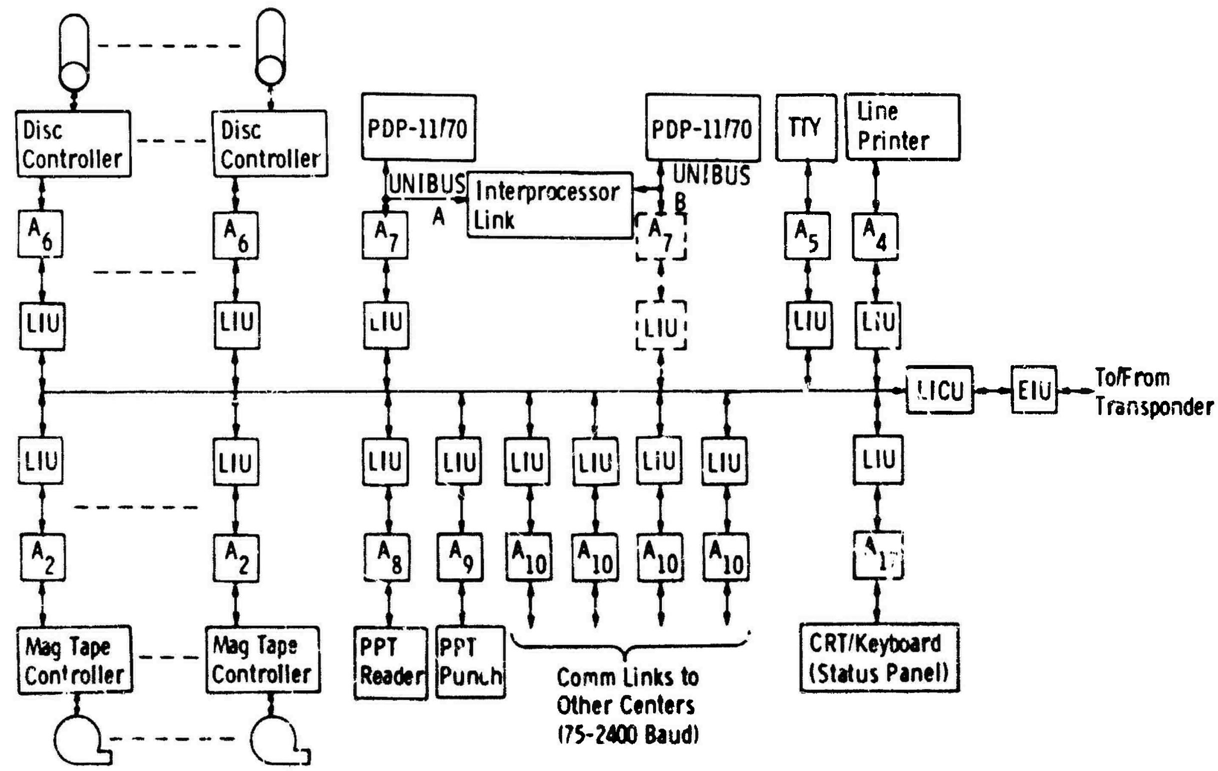


Figure 7-46. FI implemented communications processing.

The required interface of the PDP-11 UNIBUS to the FI can be accomplished by means of the adapter shown in Figure 7-47. The hardware for PDP-11 UNIBUS interfacing is similar to that of the PDP-10, with the addition of a General Device Interface (DR11-C) offered by DEC.

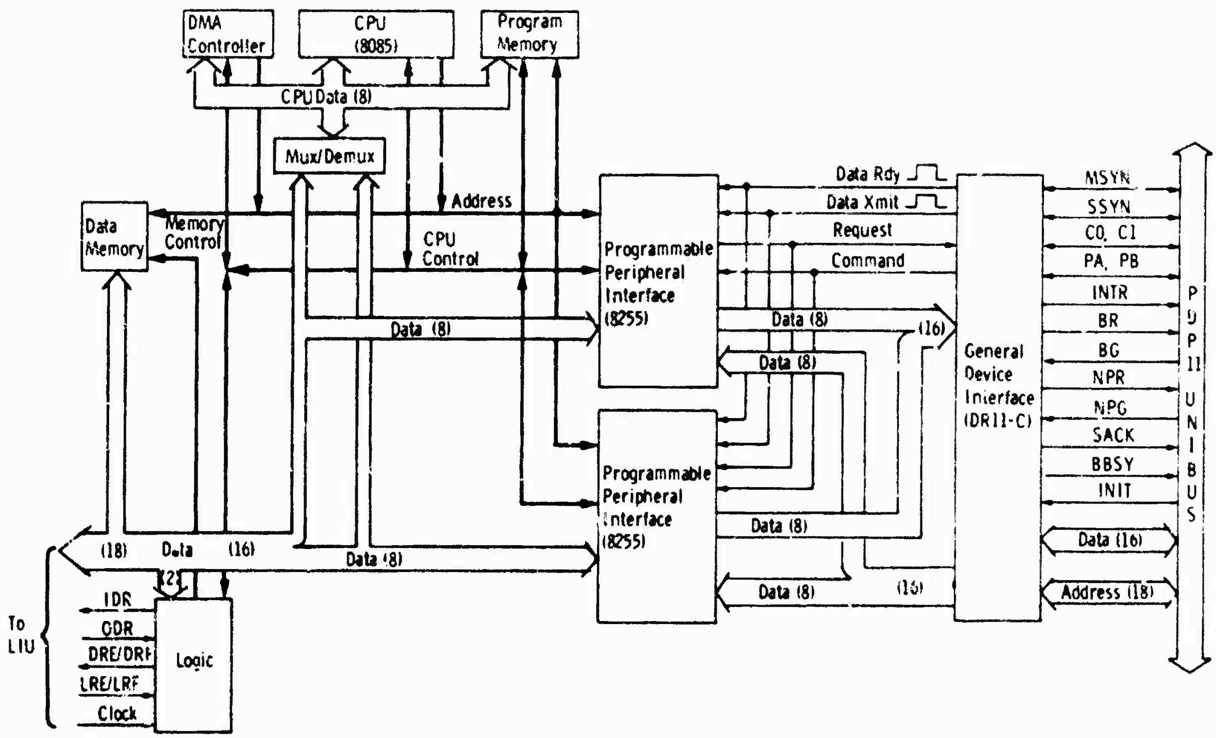


Figure 7-47. PDP-11 interface.

The DR11-C provides the logic and buffer register necessary for program-controlled parallel transfers of 16-bit data between the PDP-11 UNIBUS and an external device. It is just one of several UNIBUS interfaces offered by DEC. As with the PDP-10 adapter, the PPIs are functionally configured with software from the 8085. Data is transferred between data memory and the PPIs with the device header provided and/or interpreted by the 8085. The 18-bit format for the interface between the LIU and SAU is comprised of the 16-bit data to and from the DR11-C and 2 bits added by the SAU. Refer to Figure 7-48 for PDP-11 UNIBUS timing.

The FI configuration eliminates the need for Line Driver Units (LDU) in the communications processor. PCUs would no longer be needed since their functions would be handled in the adapters. Processors from other shelters can directly access mass storage and the peripherals without any change of cables on the FI. This can be accomplished through the protocols developed for the FI.

Communications line controller functions can be accommodated within adapters that are directly connected to modems or Special Interface Units (SIU).

The disk drives, mag tape transports, and other peripherals are similar to those in the Data Processor and can interface to the FI in the same manner as described before.

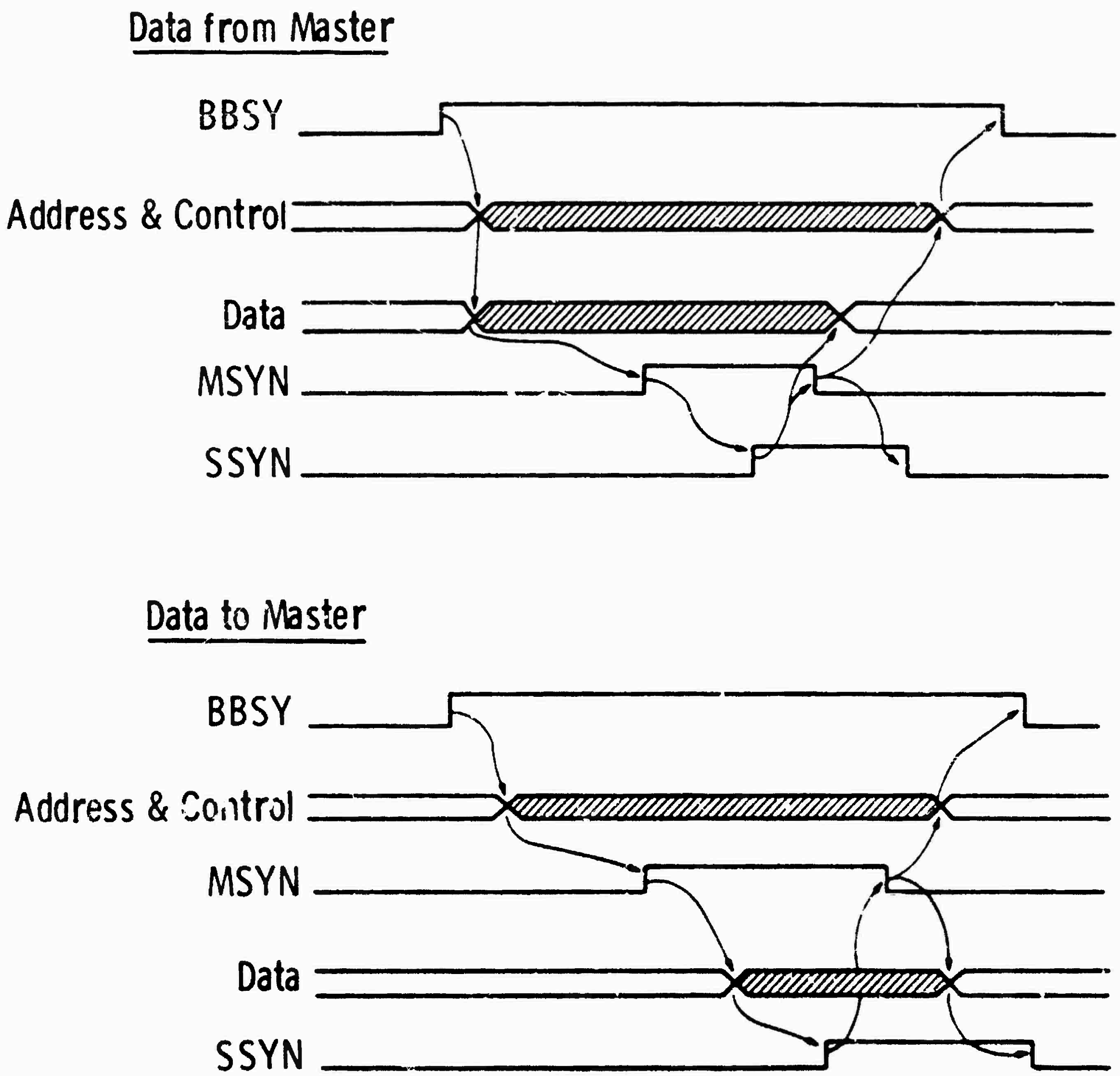


Figure 7-48. PDP-11 UNIBUS timing.

7.3 AN/GYQ-21 (V) system.

7.3.1 Background. The subject of applying the FI to military communications should not be left without mention of the AN/GYQ-21 (V) system developed by Bunker-Ramo. The AN/GYQ-21 (V) is a mini-computer based data management system developed to provide on-line interactive analysis capabilities to support command, control, communications, and intelligence functions. The system comes in various configurations tailored to user's needs and uses DEC PDP-11/series mini-computers and associated peripherals, and combinations of systems modules developed by Bunker Ramo to meet military requirements.

In 1976, the AN/GYQ-21 (V) was designated as the standard for the DOD Intelligence Community and in 1977, it was designated the WWMCCS Standard Communications Network and Front-End Processor.

7.3.2 Multiprocessor configuration. A typical AN/GYQ-21 (V) multiprocessor configuration is partially depicted in Figure 7-49.

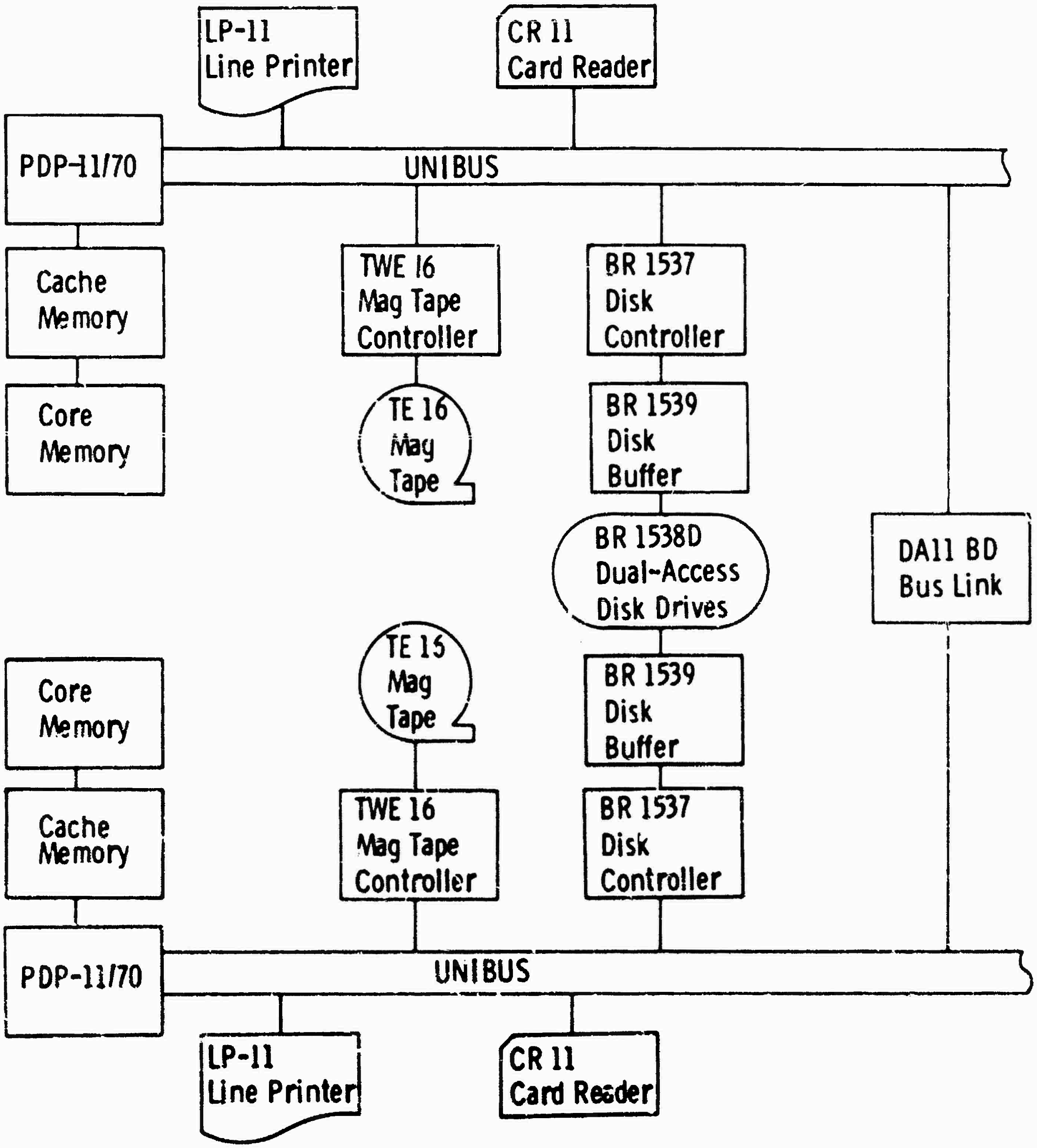


Figure 7-49. Part of AN/GYQ-21(V) system.

Two methods of processor connectivity illustrated in this example are: (1) shared memory and (2) direct memory access (DMA). Through the Bunker Ramo developed disk controller and buffer, each CPU is able to access a common data base (shared memory). A DMA parallel data transfer channel between the two CPUs is formed by the DA11-B Interprocessor Link. This link passes data lines, control information, and interrupt requests between the two processors. Data can be transferred from one CPU's memory to the other in blocks of up to 32k words.

7.3.3 FI implemented AN/GYQ-21 (V). The AN/GYQ-21 (V) system as described can be implemented on the FI (Fig. 7-50). In this configuration, a bus link between the two processors can be provided as in the original system. This would allow either CPU to transfer data from its private memory to the other.

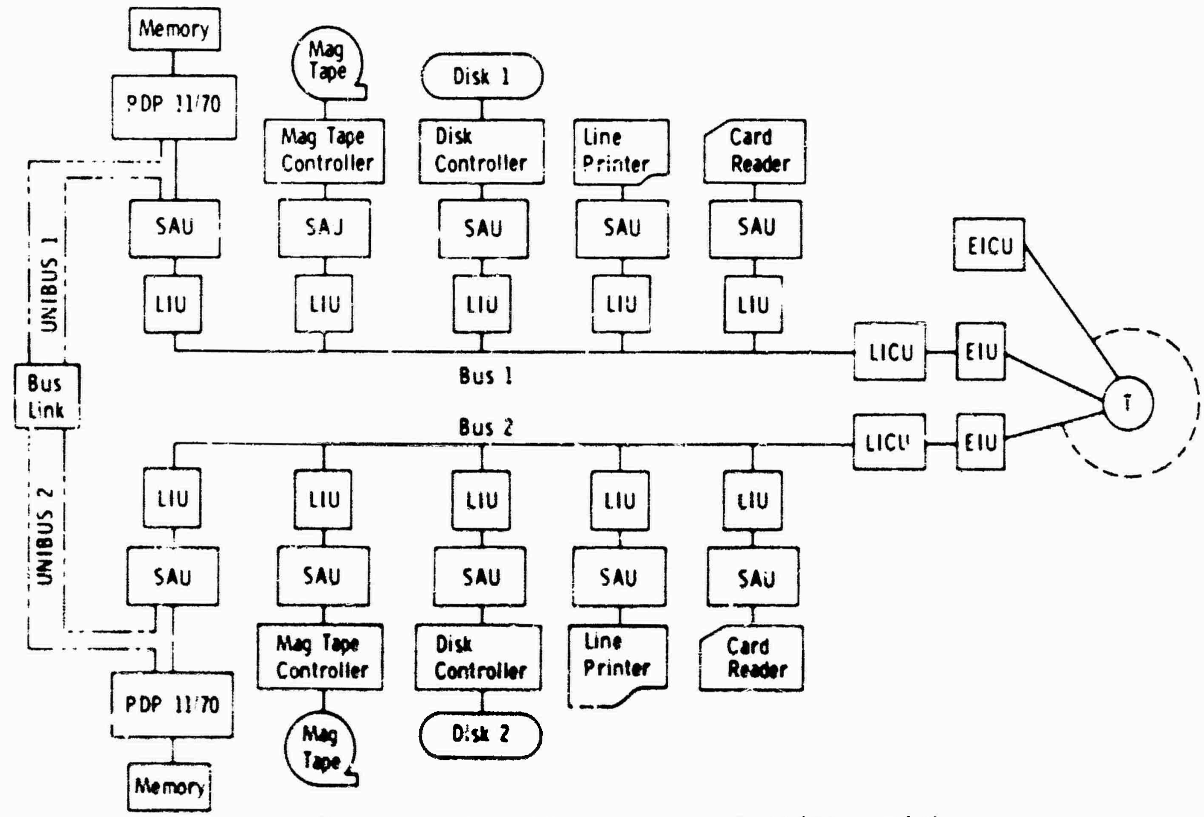


Figure 7-50. FI implemented AN/GYQ-21(V).

Each CPU can access the other as well as its corresponding peripherals via the FI link as shown. This method does not depend on processor-unique hardware such as the bus link for the UNIBUS. Access to a common data base in disk also does not depend on special disk controllers or buffers such as the BR 1537 or BR 1539.

Several possible modes of operation exist in this configuration:

7.3.3.1 Stand-alone. Each processor can operate in a stand-alone mode under its own operating system running independently with its own peripherals and database.

7.3.3.2 Back-up. One CPU can carry the entire processor load, operating with its own set of peripherals, while the other CPU runs in a stand-by mode either with its database continually updated by the other CPU or having access to a common database. If the main processor fails, the stand-by CPU, operating either with its own set of peripherals or with the other set, can assume the processing load without significant data loss.

As an implementation example, disk 1 could have half of its memory space dedicated to storing data from disk 2 and vice versa. This could allow either CPU to act as a back-up processor to the other while performing its own individual tasks.

7.3.3.3 Load sharing. A two-party protocol can be defined between the two processors to control information transfer with space in one or both disks allocated as a *mailbox* for transfer of control and status information. This allows either CPU to assign tasks to the other or to notify the other if some of its processing powers have failed. In this case the other CPU would assume that part of the processing burden.

Processing of tasks may take several forms:

a. Each CPU performs different tasks with the purpose being to decrease the processing burden on one CPU.
b. Each CPU performs identical tasks, but at separate facilities for independent users.
c. Each CPU performs tasks, identical or other wise, as required for distributed processing. For instance, both processors could operate under the same operating system to perform true distributive processing. That is, not only can each CPU process different assigned tasks (as in functionally distributed), but both CPUs can share the processing load on the same task.

7.3.3.4 Conclusion. Both the back-up and load-sharing modes of operation would allow one CPU to assume some of the other's processing burden in case of failure of some processing functions. If the healthy CPU had been processing at full capacity, it could still assume a heavier load by operating in a degraded fashion. The back-up, and functionally distributed processing modes, can be carried on between shelters as well as within a shelter, although probably in a slower (degraded) fashion.

The FI concept would allow the AN/GYQ-21 (V) to operate at data rates of up to 10Mw/s with 36-bit words within a shelter and at rates of 50Mb/s per fiberoptic channel for 5 miles outside a shelter with 7 to 18-channel availability.

Another effect of using the FI is that the system is not hardware dependent on a certain manufacturer. FI protocols and interface requirements have been developed to accommodate diverse equipments.

8.0 SUBSYSTEM IMPLEMENTATION

8.1 Scope.

The purpose of this section is to establish hardware and software functional descriptions for the various subsystems on the FI. These subsystems include the Local Intraconnect Unit (LIU), Local Intraconnect Control Unit (LICU), External Intraconnect Unit (EIU), External Intraconnect Control Unit (EICU), and the FI Manager. Since the LIU is the most prevalent subsystem on the FI, its implementation will be discussed. The hardware and software structural approach will also be applied to other subsystems.

8.2 LIU implementation.

The basic function of the LIU is to provide the interface between the Local Intraconnect (LI) and Automatic Data Processing (ADP) or Communication (COM) devices. These devices will be referred to as Data Terminal Equipment (DTE).

8.2.1 Requirements.

a. General. LIU functional requirements are summarized as follows:

- Transfer data up to 10Mw/s to and from a DTE in a DMA fashion;
- Process and verify DTE headers;
- Formulate network messages for transmission of DTE data onto the FI;
- Transfer network messages to/from the FI in DMA fashion;
- Process and verify network headers; and
- Error checking on data.

b. Interface.

1. DTE. The LIU transfers data to/from a DTE in the form of 1024 18-bit word data blocks. Each block has a device header attached to it with a fixed format as described in Section 5.3.3. Control of the transfer between the LIU and a DTE is described in the interface standard.
2. LI. The LIU transfers data to and from the LI in the form of 512 36-bit word data packets. Several reasons exist for breaking messages into packets for transmission on the FI. Transmission can start as soon as the first packet is assembled, corruption of information by noise can be better accommodated by retransmission (if required) of only the packet affected rather than the entire message, and packets can be interleaved by LIUs on the FI, thus long messages do not block transmission links.

A packet consists of the DTE data and header. A network header and trailer are added to this for control on the FI level (described in Section 5.3.3).

Control signals transmitted on the LI are used by the LIU for transferring data to and from the LI. A Data Strobe (DS) signal is a timing pulse that accompanies each data word transmitted on the LI. A Header Control (HC) signal is a pulse that accompanies both the first network header word and the network trailer word. The DS and HC are transmitted by the source LIU.

8.2.2 Functional description. The LIU is functionally structured in a modular fashion. Hardware and software functions have been identified to the block diagram level, then broken up in a hierarchical manner into functional modules. Proven design techniques will be used such that performance requirements are met in the most cost-effective manner. As shown in Figure 8-1, the hardware consists of a DTE receiver, DTE transmitter, and microcomputer; with software composed of executive, operational, diagnostic, and database functions.

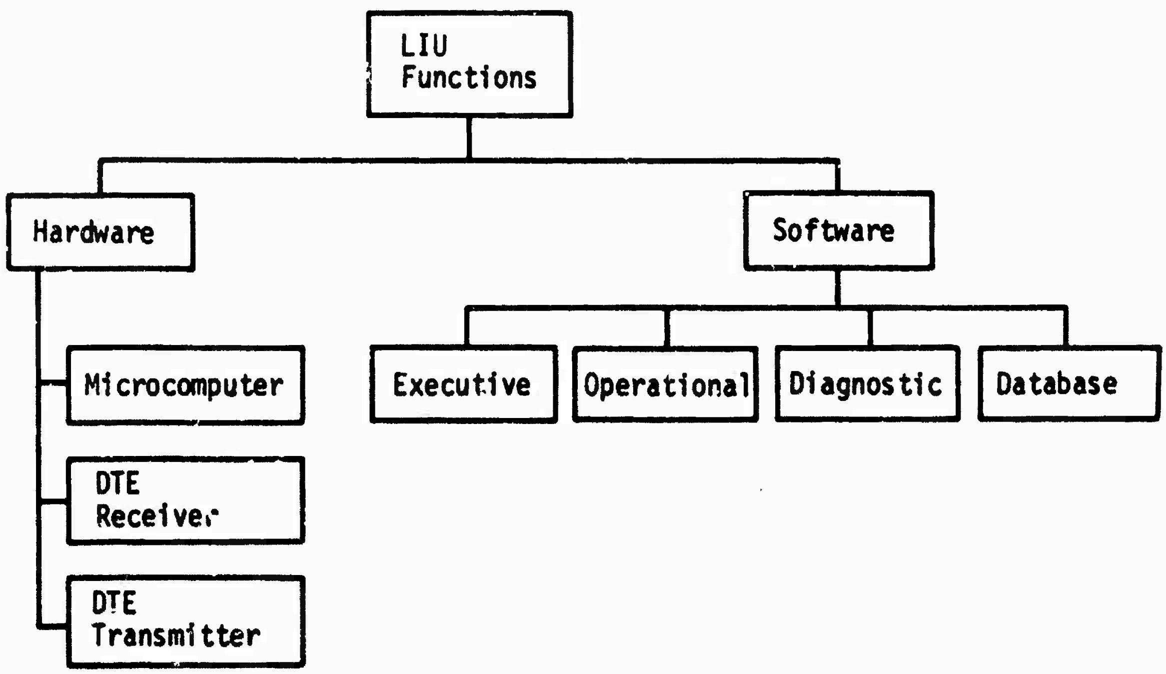


Figure 8-1. LIU functions.

8.2.2.1 Hardware.

8.2.2.1.1 Microcomputer. The LIU will be controlled by a microcomputer consisting of a CPU, main memory, programmable interrupt controller, and device selector. The microcomputer will perform tasks such as initializing the variable database, setting up DTE/LIU DMA transfers, formulating network messages for transmission on the LI, setting up LIU/LI DMA transfers, and processing network messages.

Programs (instructions) will be resident in static read-only memories (ROM) while the initialization database will be contained in static random-access memories (RAM) because it is subject to change. RAM will also be used as a scratch-pad memory for temporary storage of data being manipulated during program execution.

8.2.2.1.1.1 CPU. The CPU selected is an Intel 8085. This is an 8-bit N-channel microprocessor with the following features:

- Five instruction types - data transfer, arithmetic, logical, branch, and stack, I/O and machine control;
- Four address modes - direct, register, register indirect, and immediate;
- One accumulator, six general purpose registers, a program counter, and a stack pointer;
- Four vectored interrupts (including one nonmaskable); and
- Direct addressing capability to 64k bytes.

8.2.2.1.1.2 Programmable interrupt controller. Interrupts allow peripheral devices to transfer data when ready. This allows transfer of data on an asynchronous basis freeing the processor for other tasks while peripherals collect the data. When an I/O device has data to transfer, it signals the CPU (Intel 8085) with an interrupt request. Upon receipt of this interrupt and if the appropriate interrupt-enable bit is set, the processor suspends current program execution and responds with an interrupt acknowledge signal. The interrupting device then identifies itself, steering the CPU to the appropriate data transfer routine. Once the transfer is complete, the processor clears the interrupt request and returns to whatever it was doing before it was interrupted. The CPU has the option of accepting or ignoring interrupts based on the state of the interrupt flag, which can enable or disable the interrupt system.

The LIU will employ a vectored-priority interrupt technique rather than device polling, which occurs when the CPU interrogates each device in sequence for service requirements. Device polling could have a detrimental effect on system throughput because the LIU software may devote a large portion of its time looping through the continuous polling cycle.

The Intel Programmable Interrupt Controller (PIC) has been selected to provide overall management of the interrupt system. The PIC minimizes software and real-time overhead in handling multi-level priority interrupts by providing up to eight vectored-priority interrupts. When an interrupt request is generated, the PIC accepts the request, determines which request is of highest importance (priority), ascertains whether the request has a higher priority than that currently being serviced, and issues an interrupt to the CPU based on this determination. Control is then dispatched to the appropriate interrupt handling (service) routine. Significant features of the PIC are:

- Programmable interrupt modes;
- Individual request mask capability; and
- Dynamically changeable priority modes and algorithms.

8.2.2.1.1.3 I/O. The components and peripherals contained within the microcomputer connect to and communicate with each other on a high-speed bus. Every device on this bus communicates in the same form, i.e., the CPU uses the same signals to access memory as with peripheral devices. A memory-mapped I/O technique is employed in communicating with peripheral devices, that is, peripherals are connected to the memory control lines and respond like memory devices. They can be accessed as memory locations, using the processor's memory reference instructions rather than the I/O instructions. Memory reference instructions can either obtain data from memory or place data into memory.

While the memory reference instructions increase the flexibility of the I/O system there are some disadvantages of memory-mapped I/O. Since the I/O devices are addressed as memory, there will be fewer addresses available for memory. A further disadvantage of memory-mapped I/O with the 8085 is that it takes 3 bytes of instructions and 13 clock cycles for memory reference instructions to communicate with the I/O devices while the I/O instructions require 2 bytes and 10 clock cycles since the I/O address space is smaller (only 256 bytes). However, memory-mapped I/O provides the greater flexibility since all memory reference instructions can be used for communication with I/O devices.

Every peripheral device has a given set of unique associated addresses that are addressed as main memory. There are two types of addresses associated with each device:

- Control and status; and
- Data buffer.

Control and status addresses contain all the information necessary to communicate with a peripheral device. The data buffer address is used for temporarily storing data to be transferred into or out of the microcomputer. The number and type of data addresses is a function of the device.

8.2.2.1.2 DTE receiver. The DTE receiver is the interface between the DTE and LI which receives DTE data and transmits network messages onto the LI.

8.2.2.1.2.1 DTE Receiver Controller (DRC). The DRC shown in Figure 8-2 controls the transfer of data blocks from the DTE to the LIU. This can be explained with the aid of Figure 8-3. Upon receiving a command from the microcomputer to enable the Input Data Request (IDR) from the DTE, the DRC will monitor IDR. When IDR becomes active, a data word will be input to the receive data buffer. This input process will continue until either the terminal count is reached or IDR becomes inactive. When either occurs, a data transfer complete interrupt will be generated. If the termination of IDR and the terminal count do not occur simultaneously a word count error flag will be set. Parity error detection will also be performed while data is inputed. If an error is detected, a parity error flag will be set.

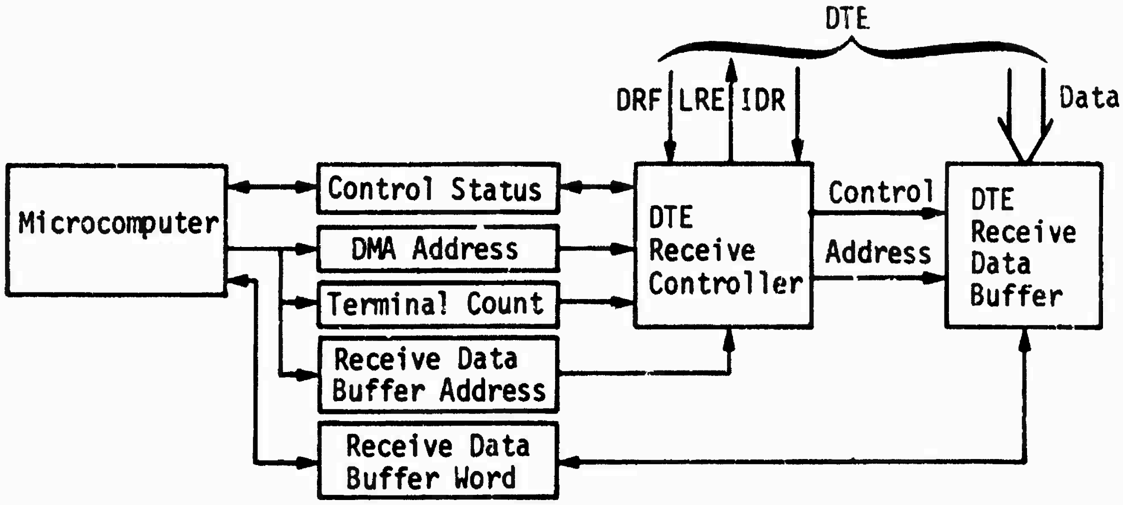


Figure 8-2. DTE receive controller.

Interface between the microcomputer and the DRC is via five registers. The control status register contains information denoting parity error, word-count error, and data-block length. The receive data buffer address register contains the location of the receive-data buffer which is to be accessed. The receive-data buffer word register contains the data word and the receive data buffer read/write status of this word.

The DRC also generates an interrupt request indicating the end of transmission of a data block or an error condition.

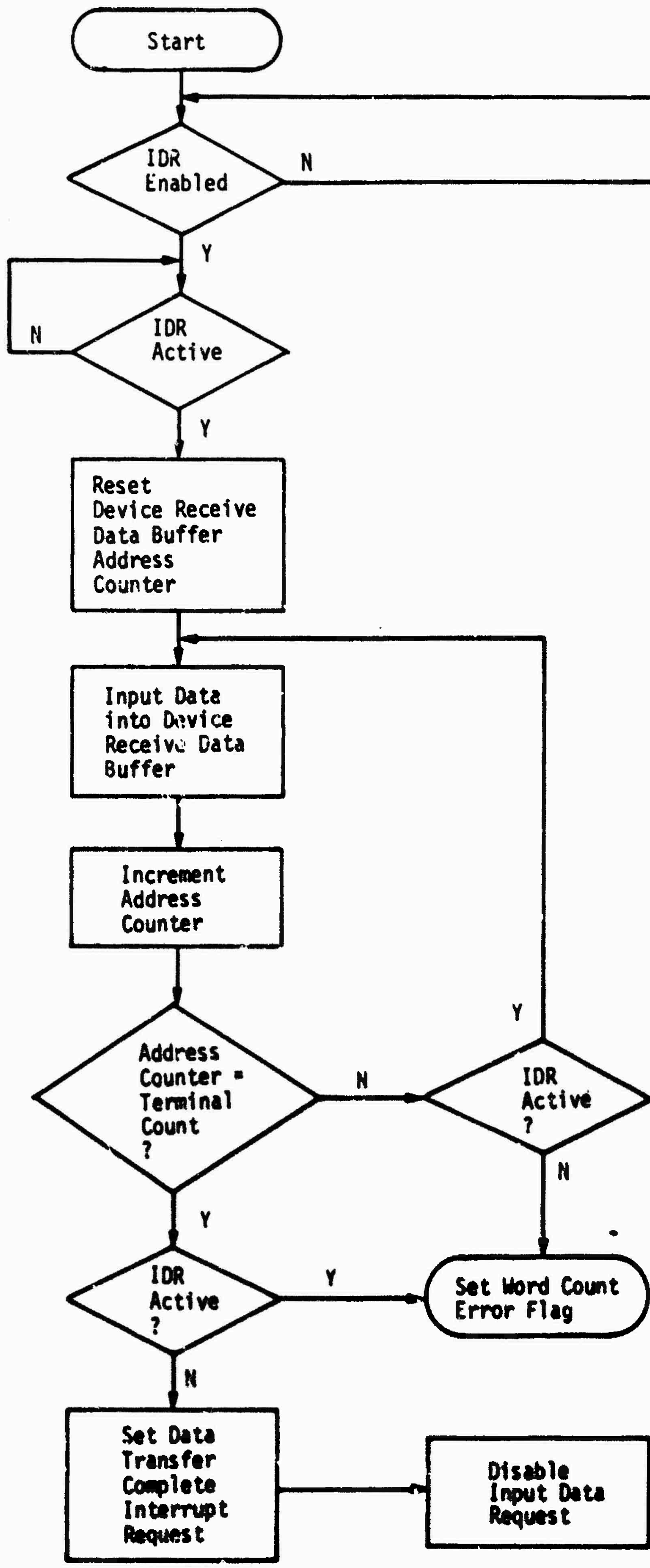


Figure 8-3. Device receive control flow.

8.2.2.1.2.2 Output Controller (OC). The OC will transfer network messages from the LIU to the LI and is shown in Figure 8-4. Upon command from the microcomputer, the proper network header and trailer contained in the output header buffer and, if applicable, the DTE data (including device header) contained in the receive data buffer are transmitted onto the LI. When the transfer is complete, an interrupt request is generated from the OC.

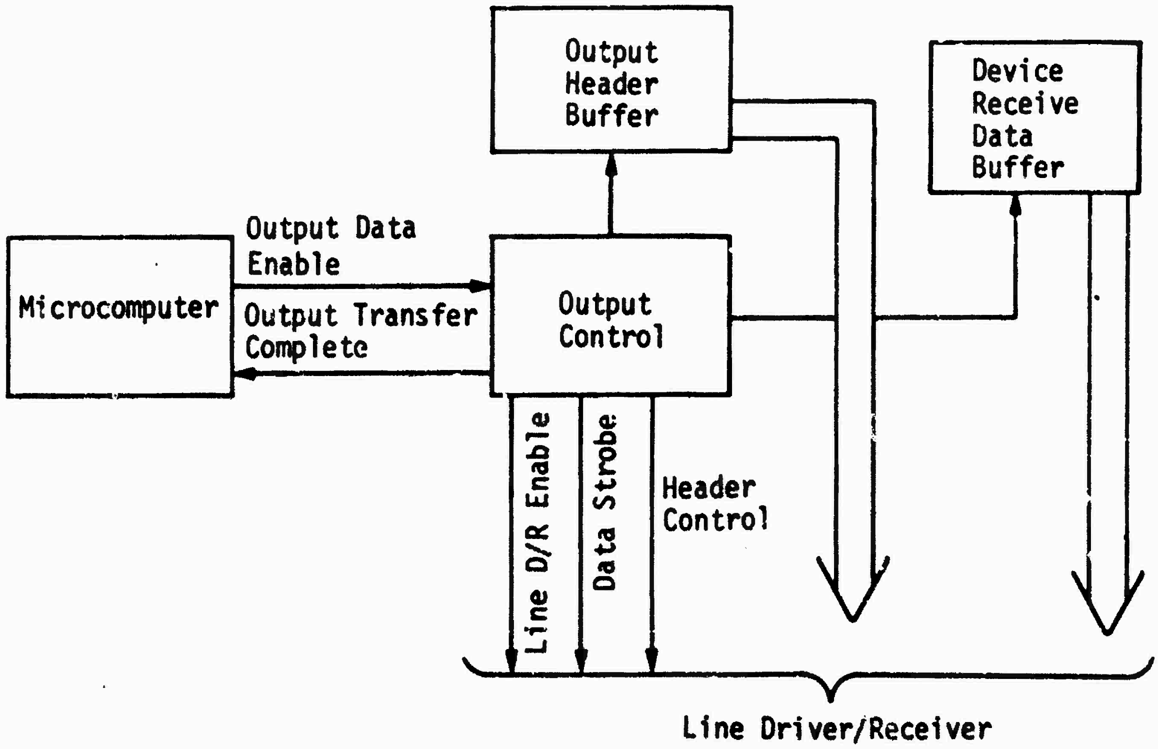


Figure 8-4. Output control block diagram.

8.2.2.1.3 DTE transmitter. The DTE transmitter processes network messages received from the LI by making accept or reject decisions based on information contained in the network header, storing the data in a transmit/broadcast data buffer if the decision is to accept, and transmitting the data to the DTE when commanded by the microcomputer. The DTE transmitter can be divided into two functions: (1) header message control, and (2) DTE transmit control.

8.2.2.1.3.1 Header message control. The header message control function inputs the network header from the LI and determines whether to accept or reject the message (Fig. 8-5).

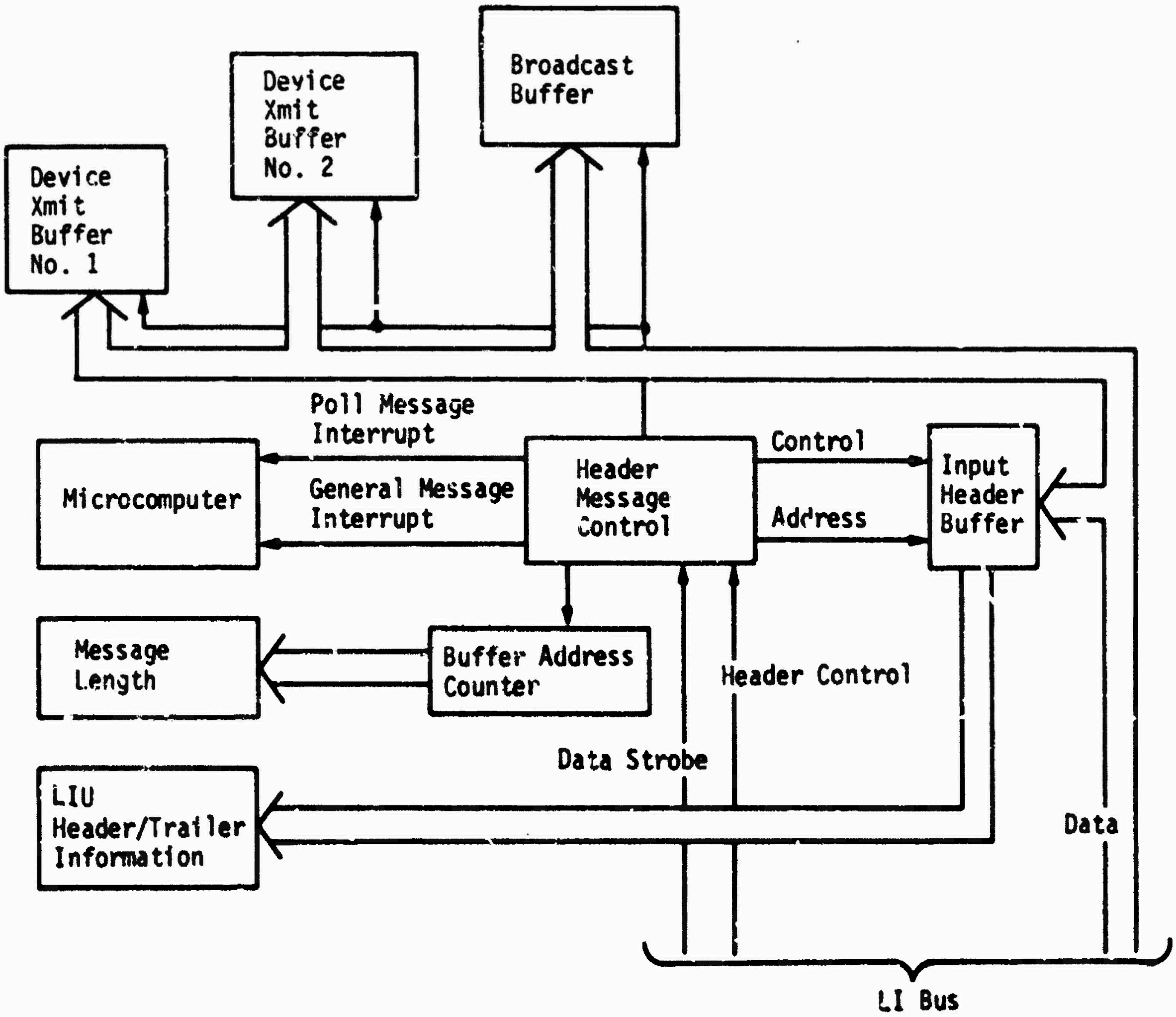


Figure 8-5. Header message control.

When data is output onto the LI by either an LIU or LICU, it is received by each LIU. When the network header is received, it is analyzed to determine whether to accept or reject the forthcoming data words. If the message is not for this LIU, the forthcoming data are ignored. Otherwise, the network header is accepted and stored in the input header buffer. The data are input and stored in either the broadcast buffer or the available DTE transmit buffer depending upon the message type. Once the trailer is detected, the message type is analyzed to determine if the message is a poll. If it is, a poll message interrupt is generated. Otherwise, a general message interrupt is generated. Error detection is performed on the network header and data while the data is being transferred. If an error is detected, an error flag is set.

8.2.2.1.3.2 DTE transmit control. The DTE transmit controller shown in Figure 8-6 transmits data to the DTE upon command from the microcomputer. When the transfer is complete, an interrupt is generated to the microcomputer.

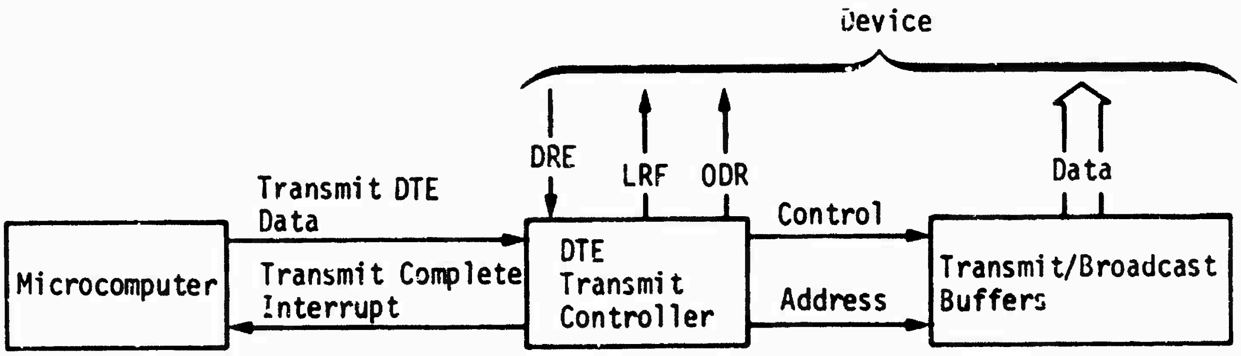


Figure 8-6. DTE transmit controller.

8.2.2.1.4 Interface. DTE interface line drivers and receivers provide tri-state switching and electrical requirements for interface between a DTE and LIU. Enabling/disabling of the bi-directional driver/receiver and output control signals are controlled by the microcomputer.

LI interface line drivers and receivers provide the necessary interface between a LIU and LI. The control lines and bi-directional data lines are controlled by the DTE receiver.

8.2.2.2 Software. LIU software is modular structured as a top-down hierarchy, being interrupt and database driven. It executes in a real-time multi-tasking environment to accomplish all the processing required. The software is to be designed so as not to be peculiar to a specific device type. The LIU software is comprised of four major functional areas(Fig. 8-7).

- Executive
- Operational
- Diagnostic
- Database

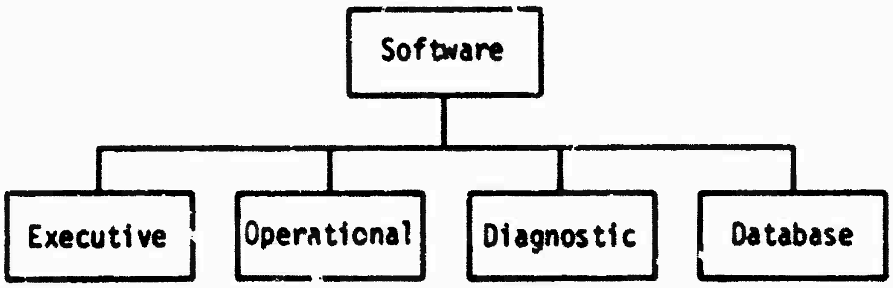


Figure 8-7. LIU software subsystem.

8.2.2.2.1 Executive subsystem. The executive software provides overall system control and management of tasks. As shown in Figure 8-8, it includes:

- Executive control which schedules tasks and processes interrupts;
- Executive service which provides services to tasks such as queue control, task request, I/O request, and memory management;
- Device drivers;
- Initialization; and
- System library functions.

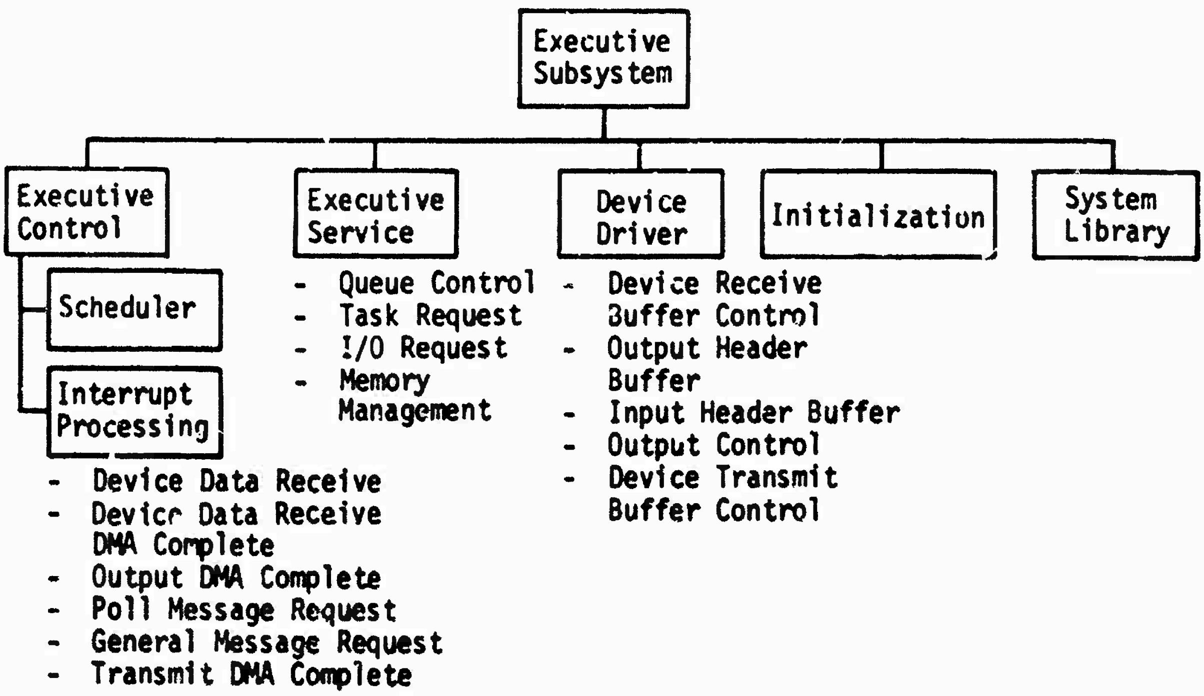


Figure 8-8. Executive subsystem

The basic unit of work which the executive facilities service is called a task. Tasks are functions that compete for system resources under the executive priority processing scheme. The priority processing scheme is used to define a task's relationship to other tasks. A task consists of one or more closed-structure procedures (i.e., function, module, or subroutine) with one of the procedures being the main procedure. Closed-structure procedures transfer control back to the control entry point. They execute a defined sequence until a terminal condition is reached. Thus, control passes into the structure through the entry point and remains until the termination condition causes control to exit through the single exit point. A procedure is a single entity with only one entry point and one exit point. The main procedure provides overall control of the task and communicates with the executive. It is called by the executive and returns to the executive when execution is complete. The main procedure also transfers control to other procedures - within the same task or global sharing. Global sharing procedures can be used by other procedures, are common in nature, and perform specific functions.

8.2.2.2.1.1 Executive control. The executive control is comprised of the scheduler and interrupt processing functions.

8.2.2.2.1.1.1 Scheduler. The scheduler (Fig. 8-9 and -10) provides the facility for handling multiple requests for service in a real-time environment. Scheduling is event-driven (interrupt), in contrast to time-slicing for determining a task's eligibility to execute. Scheduling is performed when an event occurs (interrupt) rather than at defined time intervals. The basis of event-driven task scheduling is the software priority assigned to each task. A task's priority is set at initialization.

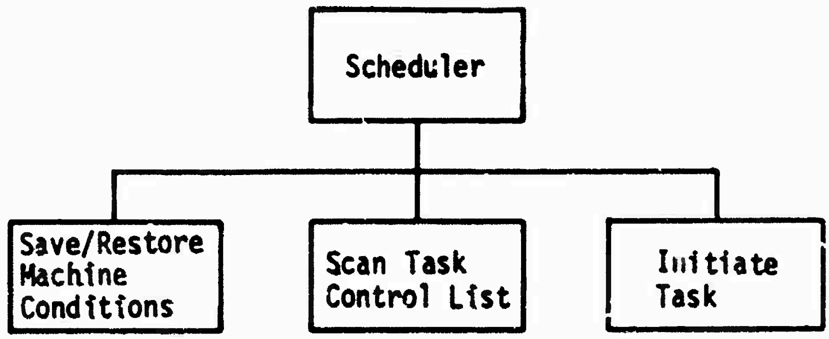


Figure 8-9. Scheduler functions.

Tasks run at a software priority level ranging from low to high. The scheduler grants the processor to the highest priority task capable of execution. That task retains control of the central processor until an interrupt occurs. When an external interrupt occurs, the scheduler interrupts the executing task and searches for a task capable of execution. The highest priority task will be executed.

When activated by an interrupt service routine, the scheduler determines if a task is running. If a task is running, the machine condition is saved and the interrupted flag is set. The task control list is searched from the top for an active task. When found, the interrupts are enabled and the task is invoked. When the task returns, the scheduler cycles through the task control list searching for the next highest active task. If the interrupted task has the highest priority, the task machine conditions are restored and task execution is resumed where it was interrupted. As long as there is processing to be done, the scheduler cycles through the task control list executing active tasks. When all processing is complete, the scheduler WAITS until activated by an interrupt service.

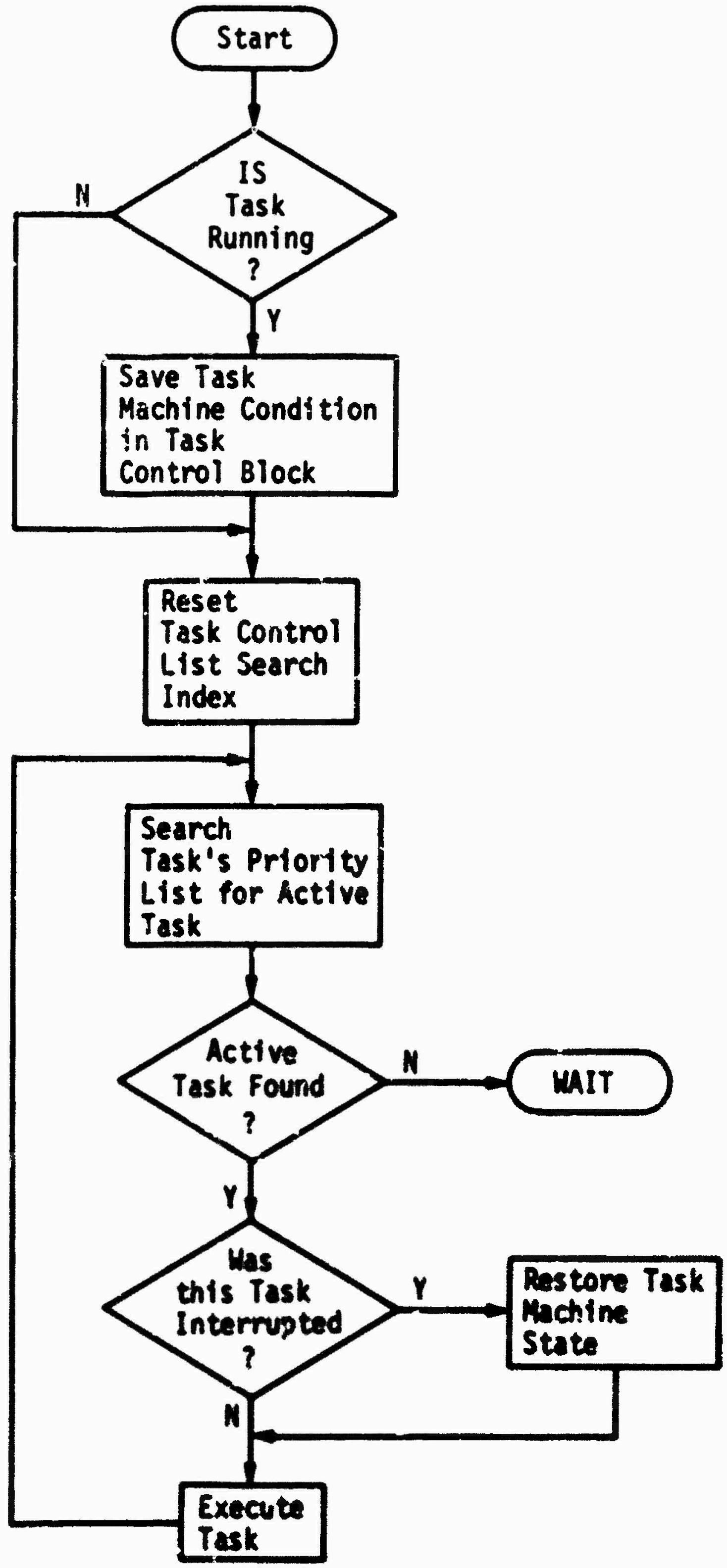


Figure 8-10. Scheduler flow.

8.2.2.2.1.1.2 Interrupt processing. The LIU I/O is based on an asynchronous interrupt technique which interrupts the processor whenever a peripheral device needs servicing (Fig. 8-11a).

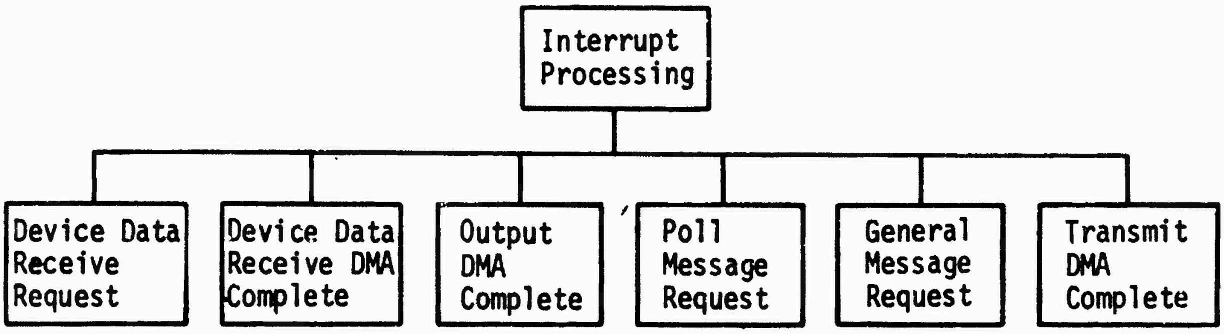


Figure 8-11a. Interrupt processing functions.

When an interrupt request is generated, it is decided if the incoming request has a higher priority value than the level being serviced. Control is vectored to the highest priority interrupt service routine. When an interrupt service function is activated, the machine condition is saved. When processing is complete, control transfers to the scheduler.

The device data receive request is activated when the device data receive buffer control recognizes an active IDR from the DTE. It performs the following functions:

- Disable ODR;
- Disable interface line drivers;
- Enable interface line receivers; and
- Command the device receive buffer control to transfer data.

When data has been transferred into the data receive buffer, the device data DMA complete function:

- Reads the device data length;
- Reads the device header data; and
- Requests the header verification task.

When data has been transferred onto the LI, the output DMA complete function:

- Enables IDR monitoring; and
- Requests the task to formulate an inactive message.

If the LI message is a poll, the poll message request function:

- Reads the network header/trailer;
- Places the time-of-day information into the output header buffer; and
- Enables the output control to transfer data onto the LI.

If the LI message is a type other than a poll, a general message request interrupt is generated causing the following to occur:

- Data block length is read from the device transmit buffer control;
- Network header/trailer is read from the input header buffer; and
- Message processing task is requested.

When the data transfer from the transmit storage buffer to the DTE is complete, the transmit DMA complete function disables the device interface line drivers and commands the device receive buffer control to monitor IDR.

8.2.2.2.1.2 Executive services. The executive provides services for task intercommunication, queue control, I/O requests, and memory management (Fig. 8-11b). Tasks issue system directives which are instructions to the executive to perform the service functions.

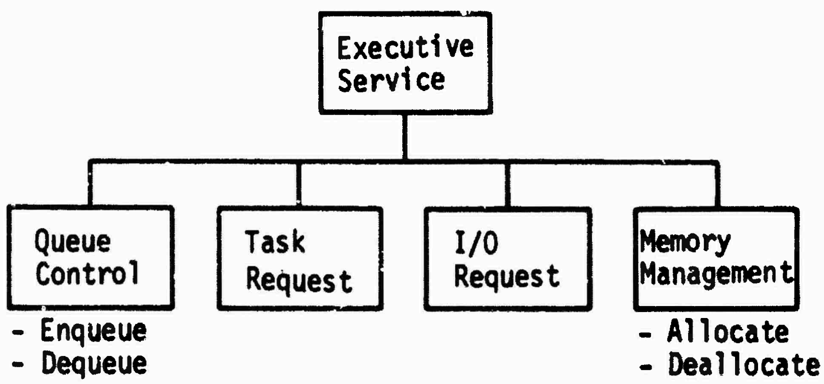


Figure 8-11b. Executive services.

Each task has an input work queue assigned to it. When a task is identified and a work packet formed, queue control attaches (enqueues) the packet to the appropriate queue. When a task is activated, it requests queue control to detach (dequeue) the work packet. The work queue is managed on a first-in first-out (FIFO) basis. Only through work packets can tasks with different priorities communicate with each other. Interrupt service routines use queue control for passing input data to tasks.

Each queue is maintained on a link list basis. A queue control exists for each queue in the task control block. The queue control contains the address of the first and last packet. Each packet contains the address of the next packet in the link. No searching is required to attach/detach a work packet. The address of the packet need only be manipulated to maintain the linkage. When a work packet is placed in the queue, its address becomes the last packet address in the task control block and the *next packet address* in the next-to-last packet in the queue.

The task request directive instructs the system to activate a task. Once activated, the task will run contingent on its priority.

The I/O request directive instructs the executive to provide an I/O operation to the issuing task. It also verifies the validities of the I/O function code and logical unit number transmitted from the caller. If invalid, an error is indicated to the caller. Otherwise, the proper device driver is called upon to perform the I/O operation.

Memory management allocates and de-allocates blocks of contiguous memory on request. Memory is allocated from a dynamic storage pool partitioned into fixed block sizes. No searching is required since the address of the next available block is maintained in a circular list.

8.2.2.2.1.3 Device drivers. Device drivers handle the physical I/O operations for a particular DTE. The I/O operations will be device and function independent. To request an I/O operation, a task issues the request via the executive to logical units previously associated with physical device units. The information supplied by the task should include the DTE logical unit, the function code (READ or WRITE), and any device-dependent parameter (command code, data buffer address, etc.).

Device drivers are either interrupt driven or I/O initiated by tasks. Interrupt driven device drivers are interrupt service routines that receive control when an interrupt request is generated. I/O initiated device drivers receive control when requested by a task via the executive to perform an I/O operation.

Several I/O initiated device driver functions have been identified to include:

- I/O operation to the device receive buffer control to read the message length and device header;
- I/O operation to the output header buffer to store the network header and trailer in preparation for transfer onto the LI;
- I/O operation to the input header buffer to accept the network header and trailer from the LI;
- Output data command to the output control to transmit data onto the LI; and
- Transmit command to the device transmit buffer control to transfer data to the DTE.

8.2.2.2.1.4 Initialization. System initialization needs to be performed at start-up and after a system failure. During this process the system is configured, peripheral devices are initialized, and the scheduler is invoked. Database initialization is required when an initialization message is received. It initializes databases peculiar to the individual LIU applications.

8.2.2.2.1.5 System library. System library routines provide commonly needed capabilities such as formulating messages and saving/restoring registers.

8.2.2.2.2 Operational software. The operational software provides the functions to fulfill the LIU requirements such as device header verification, DTE message processing, network message formulation, network header verification, and network message processing. Figure 8-12 shows the operational software functions.

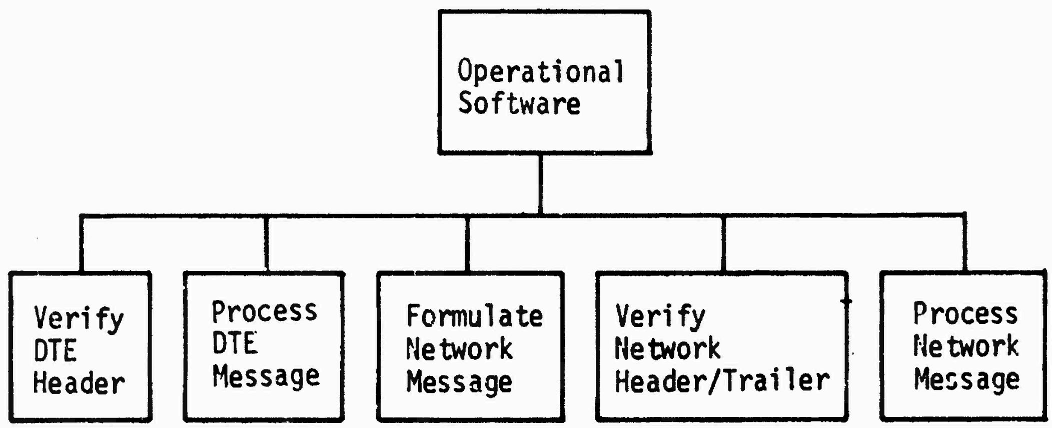


Figure 8-12. Operational software.

8.2.2.2.2.1 Device header verification. The device header verification function checks for character and block parity errors and validates the DTE header data fields (Fig. 8-13 and -14). If an error is detected, a DTE header error message is formulated, indicating the error type, for transmission to the FI Manager. If no errors are detected, a request is made to DMA the DTE data to the LIU.

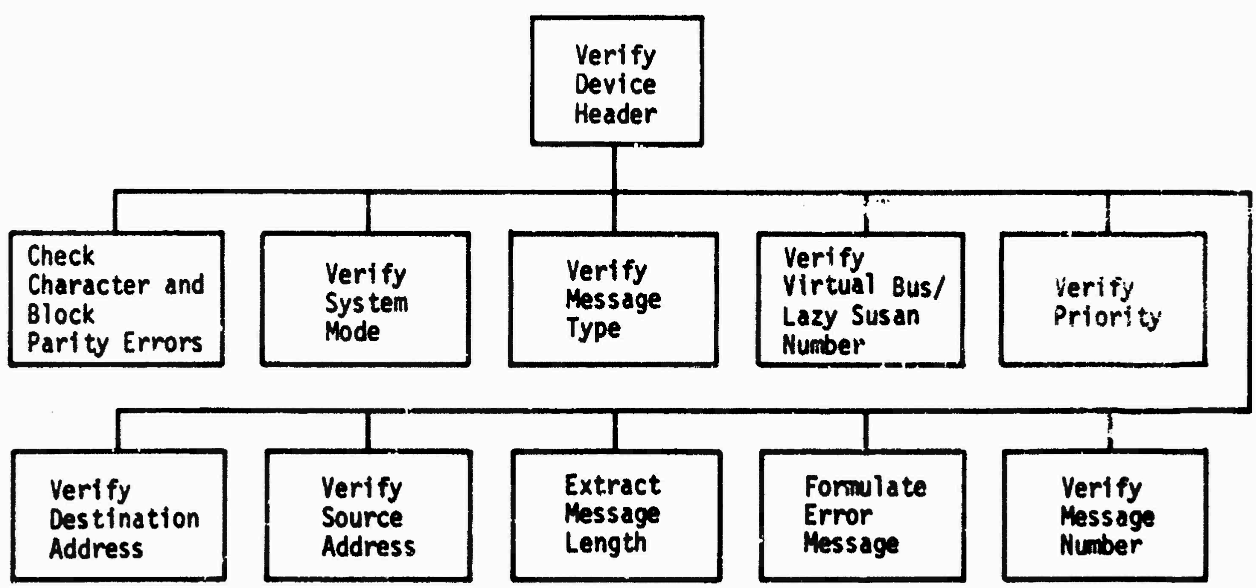


Figure 8-13. Device header verification functions.

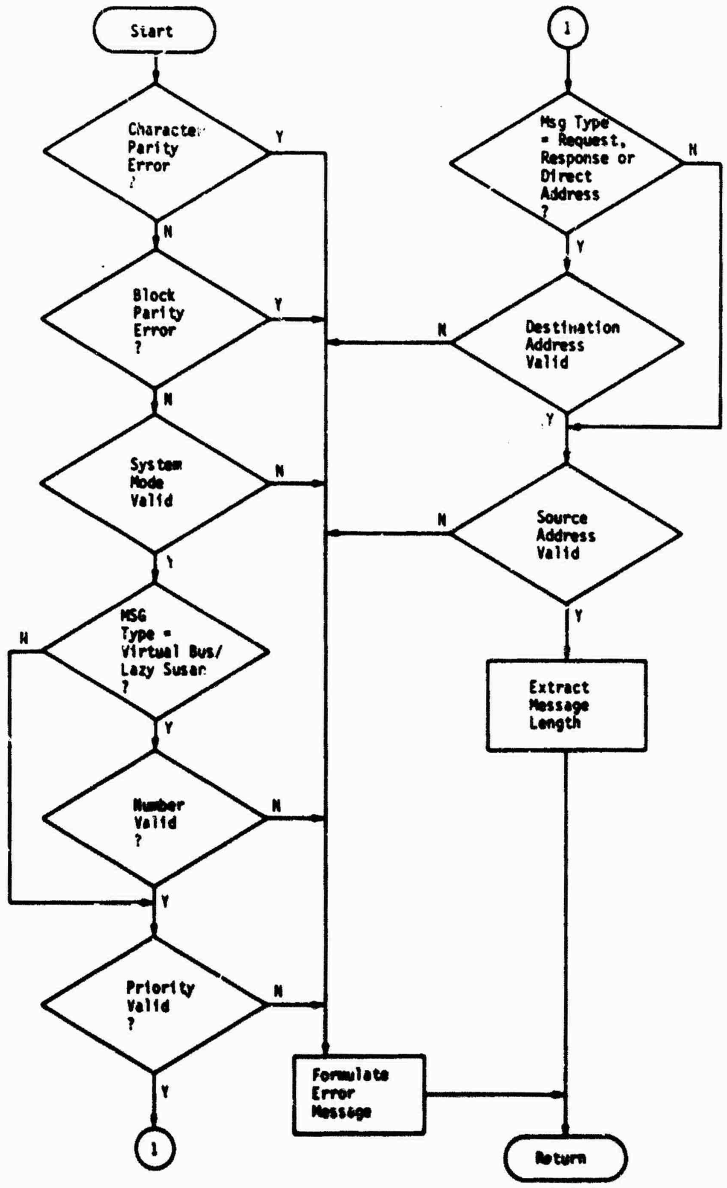


Figure 8-14. Device header verification flow.

The device header verification function performs the following:

- Checks character and block parity errors;
- Verify system mode - This field is compared to the allowable system mode. The current allowable system mode is 000;
- Verify message type - This field is compared to the allowable message type. The allowable message types are:

0010 Request Message
0011 Response Message
0100 Direct Address
0101 Virtual Bus
0110 Lazy Susan
1000 Local Broadcast
1001 FI Broadcast

- Verify virtual bus number/lazy susan number - If the message type is either a virtual bus or lazy susan, this field is compared against the allowable virtual bus/lazy susan numbers assigned by the FI manager;
- Verify priority - This field is compared to the allowable priority;
- Verify destination address - This field is validated if the message type is either a request message, response message, or direct address. The destination address is compared against the allowable destination address for the specified message types as authorized by the FI Manager;
- Verify source address - The source address is compared against the allowable source address for each message type as authorized by the FI Manager;
- Extract message length - The message length is extracted from the device header and used as a word count to DMA the DTE data; and
- Formulate error message - If an error is detected, a request message is formulated for transmission to the FI Manager. The data sent contains the error message code, the DTE virtual address where the error was detected, and the error type. The current error types are:

0000 Unused
0001 Character parity error
0010 Block parity error
0011 System mode
0100 Message type
0101 Virtual Bus/Lazy Susan Number
0110 Priority
0111 Destination Address
1000 Source Address

- Verify message number - The message number is compared to the next transmission message number. If the message number is incorrect, an error message is formulated. The message number is replaced with the transmission message number so that it is output when polled.

8.2.2.2.2.2 DTE message processing. The DTE message processing function is concerned with messages between the DTE and its associated LIU only. For instance, one of its tasks is to formulate a message with date/time information for transmission to the DTE. Another example occurs when the LIU cannot empty its data buffer on the LI because the destination continues to have no buffer available. The DTE can transmit a message to the LIU commanding it to cancel the current operation and prepare for a new one.

8.2.2.2.2.3 Network message formulation. The network message formulation function constructs the network header and trailer for transmission onto the LI when polled. The network header precedes data onto the LI and the trailer follows the data. As shown in Figure 8-15, this function performs the following:

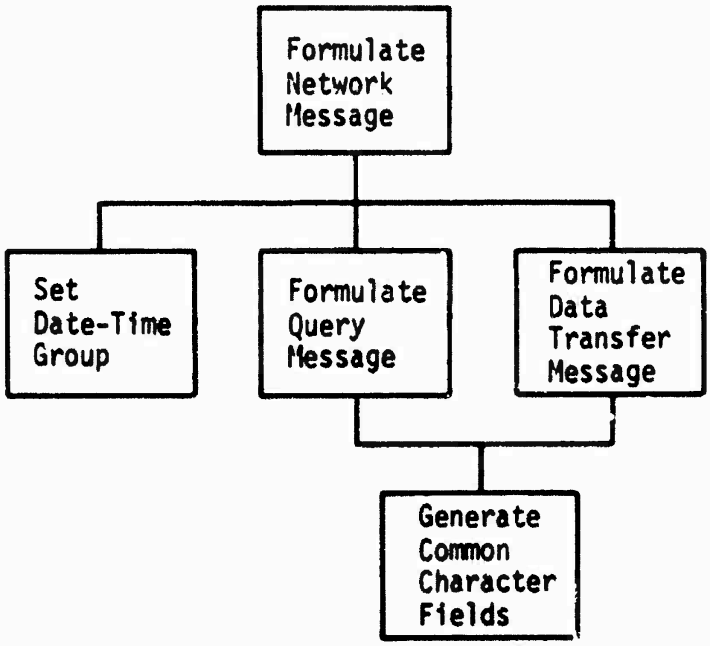


Figure 8-15. Network message formulation.

8.2.2.2.2.3.1 Set date/time group. The date/time, of which the 16 least significant bits reside in a date/time counter and the remaining 36 bits in a location in memory, is obtained and placed in the device header.

8.2.2.2.2.3.2 Formulate query message. If the DTE data is a point-to-point (direct) data transfer, a query message is formulated for transmission to the destination to obtain buffer availability status of the destination input buffers. The following fields are generated:

- Start of message
- Message type
- LIU destination address
- Number of words in header
- LIU source address
- End of message
- Block parity

8.2.2.2.2.3.3 Formulate data transfer message. Data transfer messages are formulated for direct address, local broadcast, FI broadcast, virtual bus, and lazy susan transmissions. The fields generated are:

- Start of message
- Message Type

  Direct address
  Local broadcast
  FI broadcast
  Virtual bus
  Lazy susan

- Destination address

  Direct address - 6 bits for receiving LICU + 6 bits for receiving LIU
  Broadcast (Local/FI) - Not used
  Virtual bus - Virtual bus number
  Lazy susan - Lazy susan number

- Source Address

  Direct address - 6 bits for transmitting LICU + 6 bits for transmitting LIU
  Lazy susan - 6 bits for transmiting LICU + 6 bits for transmitting LIU

- End of message
- Block parity

8.2.2.2.2.3.4 Generate common character fields.

- Start of message - Start of message is a unique 8-bit code identifying the start of a network message and is identical for each transmission;
- Message type - Message type is an 8-bit code identifying the type of network message being transmitted onto the LI;

- Destination address - This is the address of the LIU for which the message is destined and is message type dependent. For direct address and lazy susan messages, it consists of 6 bits for the LICU and 6 bits for the LIU. For virtual bus messages, it represents the virtual bus number. This field is not used for broadcast messages;
- Source address - This is the address of the transmitting LIU. It consists of 6 bits for the LICU and 6 bits for the LIU;
- End of message - End of message is a unique 8-bit code indicating the end of the network message and is identical for each transmission; and
- Block parity - The block-parity field contains vertical parity bits on the network header.

8.2.2.2.2.4 Network header verification. After a message has been accepted, its network header must be verified. If an error is detected, an error message is formulated and transmitted to the FI Manager. This function performs the following:

a. Check network header parity - The vertical and horizontal parity calculated while receiving the network header is compared against the parity information contained in the network header.
b. Formulate error message - If a parity error is detected in the network header, a request message is formulated for transmission to the FI Manager. This message contains the error message type, destination LIU virtual address, and error code.
c. Check message length - The message length determined while receiving the network header is compared to the message length information contained in the network header.

8.2.2.2.2.5 Message processing. During the processing of a message, the following functions will be performed (Fig. 8-16).

a. Check poll response - If the message is a poll response, it must first be determined if it is a query, lazy susan buffer available, or lazy susan buffer unavailable message, then the corresponding process is invoked.
b. Check query response - If the message is a query response it must first be determined if it is a buffer available or buffer unavailable message, then the corresponding process is invoked.
c. Check data transfer - If the message is a data transfer, it must first be determined if it is a direct address, virtual bus, or broadcast message, then the corresponding process is invoked.

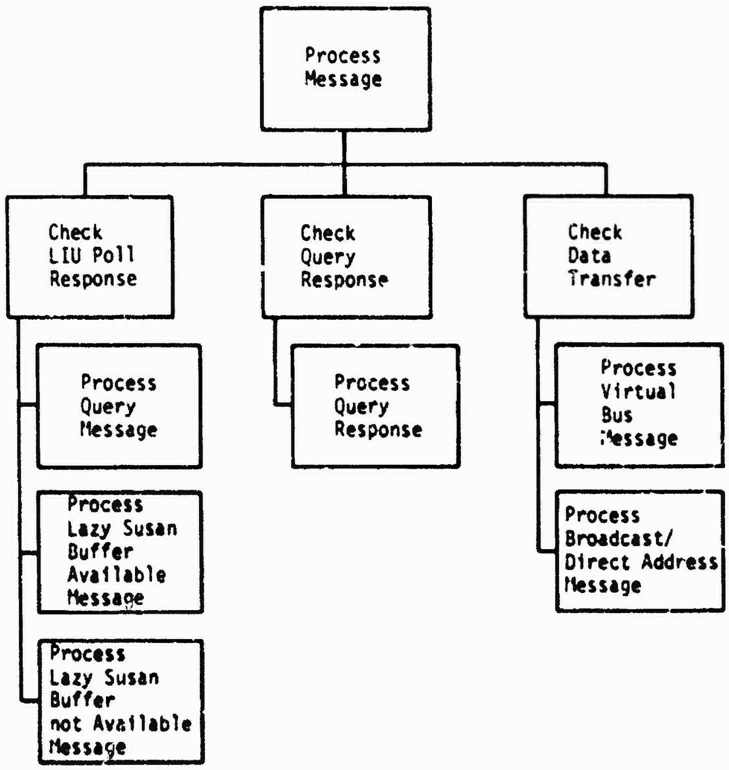


Figure 8-16. Message processing functions.

8.2.2.2.2.6 To process a virtual bus message (Fig. 8-17 and -18), the following will be performed:

a. Update real-time count - The LIU maintains a real-time count for each virtual bus to which it is assigned. When this count matches the transmission message number assigned to its corresponding DTE, the LIU transmits a message on the virtual bus.

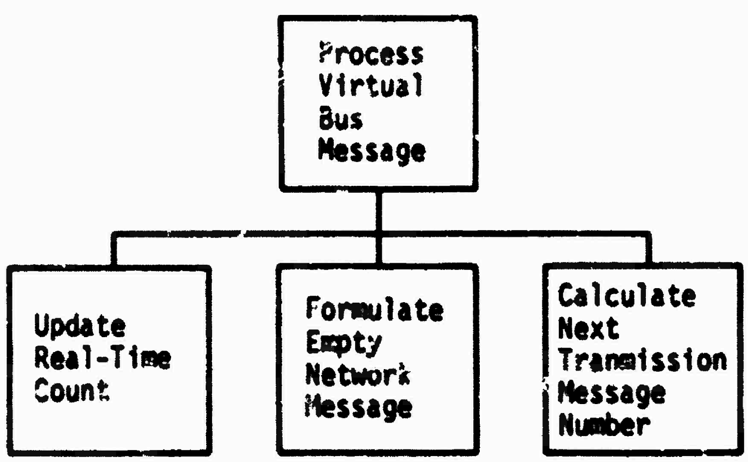


Figure 8-17. Virtual bus message process functions.

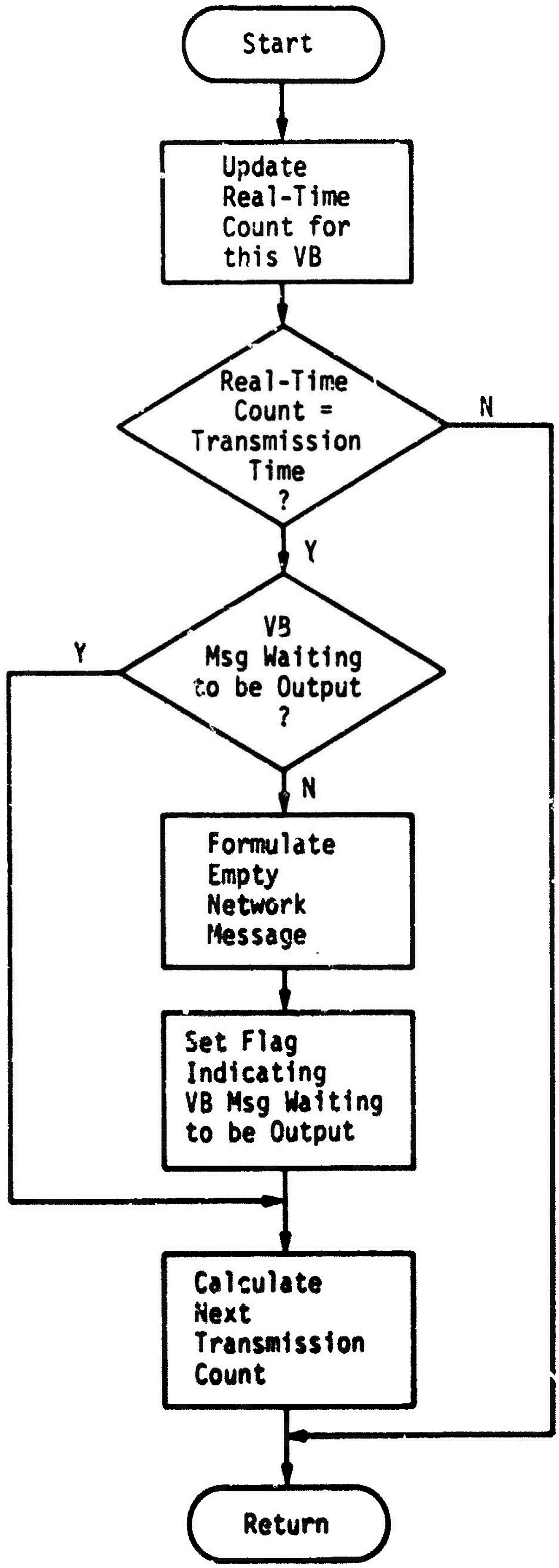


Figure 8-18. Virtual bus message process flow.

b. Formulate empty network message - If the DTE has no message to send at its assigned sequence number (transmission message count), the LIU formulates an *empty* message for output onto the LI at the next poll of this virtual bus. The empty message contains the proper network header and DTE header with the appropriate virtual bus number and current sequence number.

c. Calculate next transmission message count - The next transmission count is calculated as follows:

Transmission message count =
Starting sequence number + (N x repetition rate)

where N is a modulo 16 number representing the number of messages previously transmitted on the identified virtual bus. The starting sequence number and repetition rate is assigned by the FI Manager when the virtual bus is established.

8.2.2.2.2.7 To process a query message (Fig. 8-19 and -20), the following will be performed:

a. Check buffer availability - The transmit buffer status is checked to determine if it is available or not.

b. Queue destination address - The querying LIU address is queued on a FIFO basis. Any address appears only once in the queue.

c. Formulate buffer not-available message - When a buffer is not available or, if available, the querying LIU address is not at the top of the queue, a buffer not-available message is formulated for transmission to the querying LIU.

d. Formulate buffer-available message - If a buffer is available and the querying LIU is at the top of the queue, a buffer-available message is formulated for transmission to the querying LIU.

e. Dequeue destination address - When a buffer-available message has been transmitted to a querying LIU, its address is dequeued (if it had initially been in the queue).

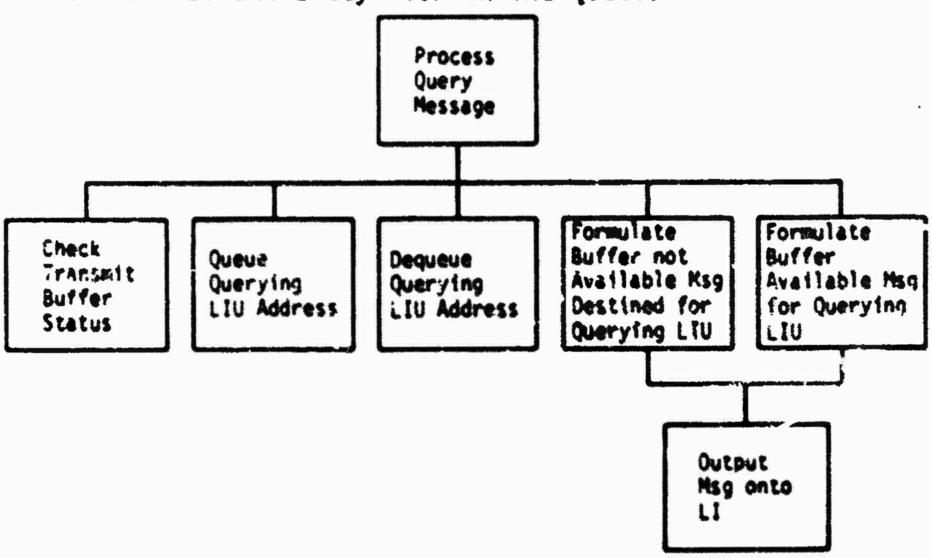


Figure 8-19. Query message process functions.

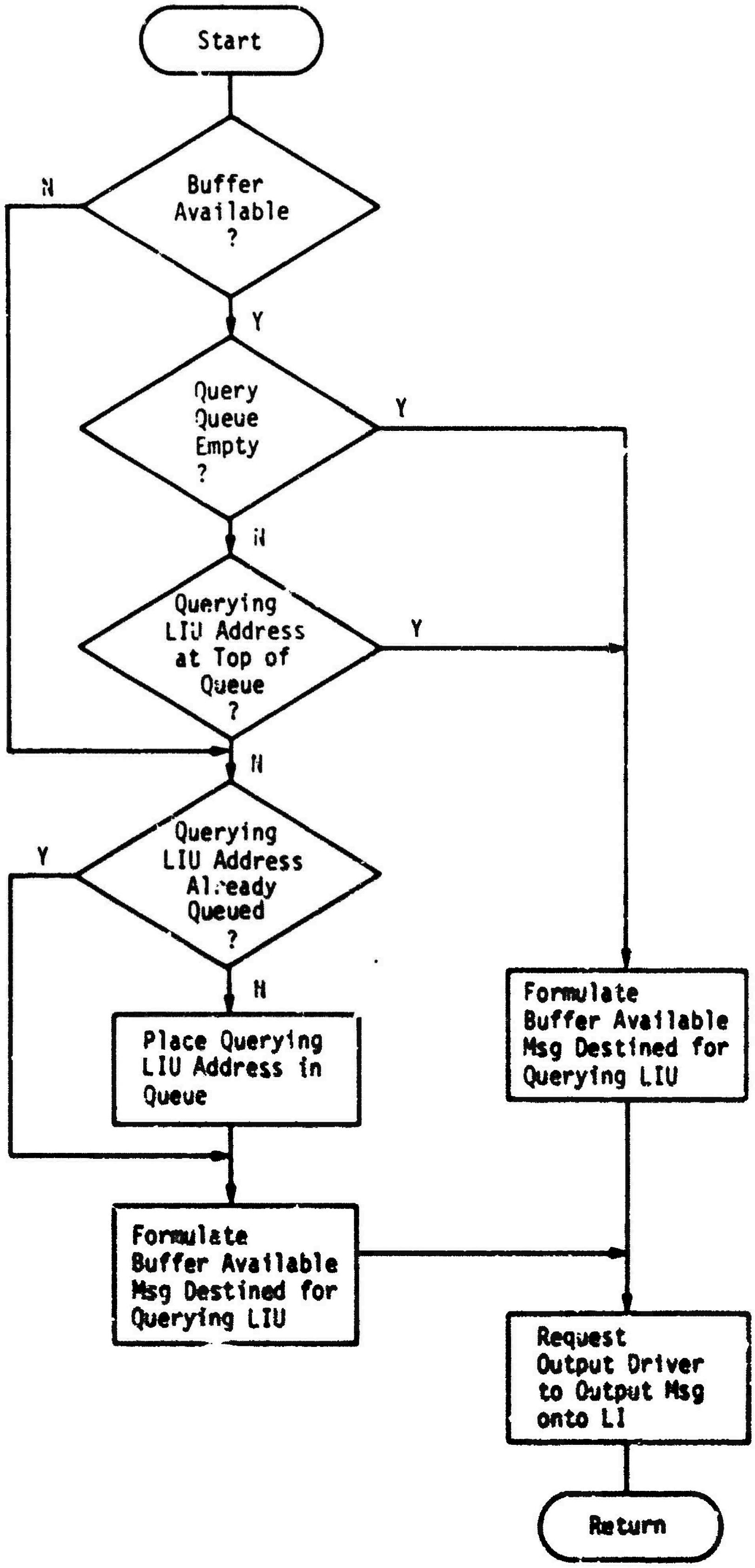


Figure 8-20. Query message process flow.

In processing a query response message, the LIU will transmit its data if the response indicates that a buffer is available. If no buffer is available, the LIU will wait to be polled again. Any further action, while waiting for the poll, such as cancelling the operation if a certain time lapses before buffer is available, can be accommodated in communications between the DTE and its LIU.

8.2.2.2.3 Diagnostic software. The diagnostic software detects and reports faults in the LIU and/or DTE. As shown in Figure 8-21, the diagnostic software is comprised of the LI diagnostics and DTE interface diagnostics. These functions execute on a continuous periodic cycle.

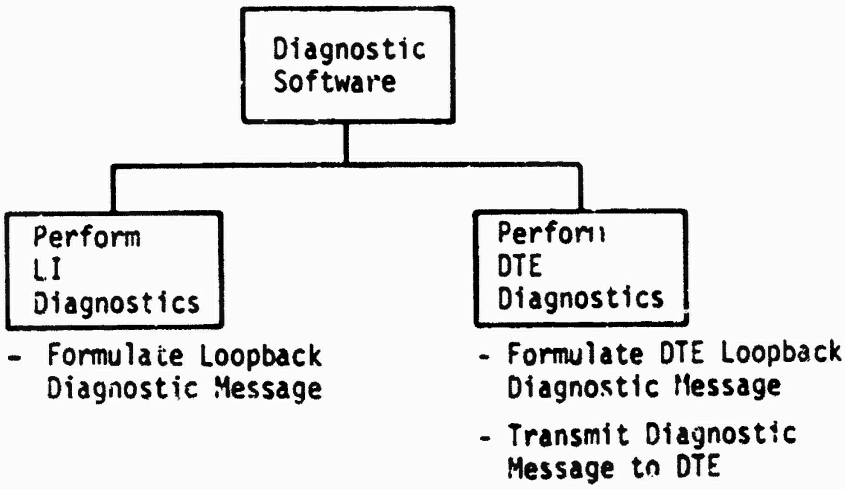


Figure 8-21. Diagnostic software functions.

The LICU will periodically transmit a diagnostic message to each LIU in an established sequence. The message will direct the LIU to return a status response message at the next poll. From the status response message, the LICU will determine the LIU availability status. The LICU will maintain a status block for each LIU. The status block will be updated, if required, at the end of each diagnostic cycle. If, at the next LIU poll, the LIU does not output a response message, the LICU will mark the LIU out of service.

When the LICU diagnostic message is received, a diagnostic response message will be formulated destined to the LICU. The LIU will then await the LICU poll. The response message will contain the loopback diagnostic word along with the DTE status.

The DTE will also periodically output a diagnostic message to the LIU to determine its availability status. When the LIU receives the DTE diagnostic message request, it will formulate a loopback diagnostic message with the message received, and transmit it back to the DTE. If the DTE does not receive the loopback message within a specified time or if the received message is in error, the LIU will be marked out of service by the DTE. Likewise, if a diagnostic message is not received from the DTE within a specified time interval, it will be marked out of service by the LIU.

8.2.2.2.4 Database. The database is a collection of information structured to facilitate the configuration of LIU operational functions. It provides the internal interface between tasks. A data structure is the manner in which the data and addresses used for program operations are organized in the system (main) memory. Each individual member of a data structure is called a data element consisting of several words. The database is divided into three categories: (1) generation, (2) initialization, and (3) operational. Generation data structures consist of internal data that does not have to be loaded. Initialization data structures contain data peculiar to the system and are loaded upon powerup or after a system failure. Operational data structures consist of data elements generated during system operation. Figure 8-22 identifies database software.

8.2.2.2.4.1 Initialization. The initialization database contains data necessary to identify the characteristics of the DTE. It is loaded upon start-up or after system failure.

Data contained in the DTE status table indicates device types, features, and operating conditions including privileges and restrictions. Each device has an entry in the DTE status table called a DTE status block which can be accessed by a DTE status block number. These numbers are assigned in sequential order. The information contained in a status block includes:

a. Device type - indicates if DTE is a communication or ADP device;
b. Priority - indicates the highest allowed priority level;

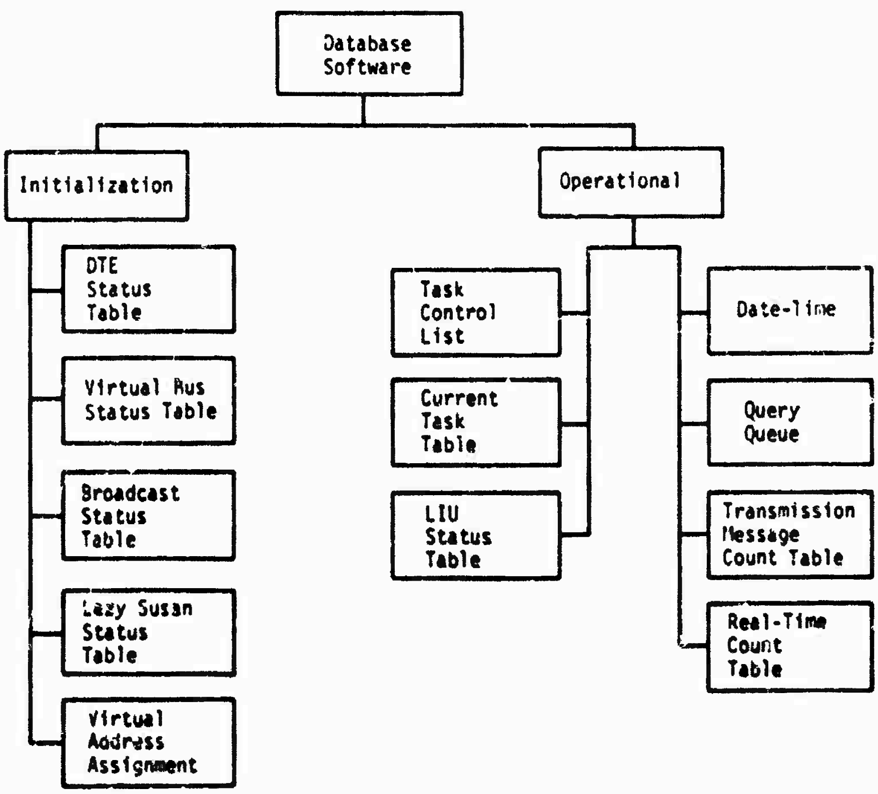


Figure 8-22. Database software.

c. State - indicates if the DTE is active/inactive and in-service/out-of-service;
d. Source virtual address - lists the virtual addresses of devices which the DTE is allowed to receive from;
e. Destination virtual address - lists the virtual addresses of devices to which the DTE is allowed to transmit;
f. Virtual bus assignment - lists the virtual buses the DTE is assigned to and its mode of communication on each one, i.e., receive only, transmit only, both, or monitor;
g. Broadcast assignment - indicates the broadcast network (LI or FI) the DTE is assigned to and its mode of communication;
h. Lazy susan assignment - lists the lazy susan loops the DTE is assigned to and its mode of communication on each;
i. Message size - indicates the maximum message size allowed to be transmitted;
j. Message rate - indicates the maximum rate in which data is to be transmitted;
k. Transmission mode - indicates if the transmission is synchronous/asynchronous and half/full duplex:
l. Transmission message number - lists the starting sequence number and repetition rate for each assigned virtual bus; and
m. Message type - indicates allowable message types.

For each virtual bus on the FI, the virtual bus status table lists the maximum message length, data rate, transmission mode, and number of assigned devices with their associated virtual addresses. Each virtual bus has an entry in this table which can be accessed by the virtual bus number.

For each broadcast network, the broadcast status table lists the maximum message size, data rate, transmission mode, and virtual addresses of each assigned DTE.

For each lazy susan loop on the FI, the lazy susan status table lists the maximum message size, data rate, and virtual addresses of each assigned DTE.

The virtual address assignment table identifies the real (FI) address associated with each virtual address.

8.2.2.2.4.2 Operational. The operational database consists of data structures that are liable to change as data passes through an LIU.

The task control list is a priority-ordered list composed of task control blocks. This list is used to determine which task to give the CPU control to after an interrupt occurs. A task control block is assigned to each task and is divided into three sections: (1) Task state, (2) queue control, and (3) machine conditions.

The task state contains the following information:

a. Entry point address - The address at which the task is initiated;
b. Interrupt status - Indicates that the task has been interrupted and must be resumed from the point of interruption; and
c. Active status - Indicates that the task is eligible for scheduling, i.e., it is ready to run and compete with other tasks for CPU time on a priority basis.

Queue control contains: (1) the first packet address which is the pointer to the first packet queued to a task, and (2) the last packet address which points to the last packet in the same queue.

An area is also set aside to save the machine conditions when a task is interrupted. It saves the status of the program counter, stack pointer, condition flags, accumulator, and all general registers.

The current task table indicates if a task is running when an interrupt occurs. When a task is invoked by the scheduler, its name and priority are entered into the current task table.

The LIU status table contains the following information:

a. LIU status - Indicates if LIU is in-service/out-of-service;
b. DTE status - Indicates if the associated DTE is in-service/out-of-service;
c. Transmit buffer status - Indicates if the transmit buffer is available;
d. DTE parity error - Indicates if a parity error was detected in the data field (includes device header and data);
e. Network header error - Indicates if an error was detected in the network header; and
f. Message length - Indicates the number of words received.

A location in the database is allocated for the 36 most significant bits of the date-time group. The bits are right justified, i.e., the right-hand bit of the first word is the least significant. Since the date-time is expressed in microseconds with the 16 least significant bits contained in a separate counter, this location is updated every 65536 microseconds.

The query queue is a temporary storage area containing the addresses of querying LIUs. It operates on a FIFO basis, i.e., the first querying LIU address queued is the first address dequeued. The queue size will be determined by traffic analysis and will consist of a header and various entries which will hold the querying LIU addresses. The header will contain: (1) A pointer to the top entry, (2) a pointer to the bottom entry, and (3) upper and lower limit addresses. The bottom pointer will be used to queue an entry, then updated to the next entry. It will be reset when it reaches the lower limit address. The queue is full when the bottom pointer reaches the lower limit address and the top pointer equals the upper limit address. The top pointer will be used to dequeue an entry, then updated to the next entry. It will be reset when it reaches the lower limit address. The queue is empty when the top and bottom pointers are equal.

The transmission message count table contains the transmission message count for each virtual bus assigned to an LIU and can be accessed by the virtual bus number. When the transmission message count is equal to the real-time count, the LIU is eligible to transmit a virtual bus message. The transmission message count is then updated to its next assigned value.

The real-time count table contains the real-time count for each virtual bus assigned to an LIU and can be accessed by the virtual bus number. It is updated each time a virtual bus transmission is detected.

8.2.3 Memory Requirement. The LIU employs two types of memory to satisfy its storage requirements. All programs (instructions) are resident in Read-Only Memory (ROM) while the database and temporary storage are contained in Random-Access Memory (RAM).

The memory requirement is estimated as follows:

Functions	Memory Requirements (Bytes)
Executive	
Scheduler	300
Interrupt Processing	400
Queue Control	200
Task Request	100
I/O Request	100
Memory Management	300
Peripheral Device Drivers	400
Initialization	200
System Library Routines	100
Operational	
Verify DTE Header	500
Process DTE Message	200
Formulate Network Message	1000
Verify Network Message	100
Process Network Message	1000
Diagnostic	
LI Bus Diagnostic	200
DTE Diagnostic	200
Database	
Initialization	6000
Operational	500
Temporary Storage	500
	12,300

9.0 SECURITY CONSIDERATIONS

The Modular C3 Interface Analysis has resulted in a preliminary design for a Flexible Intraconnect (FI). This analysis and design have indicated a requirement to protect FI information from tampering, breach of privacy and jamming.

Prevention of data interception has lead to the inclusion of communication security (COMSEC) equipment within the FI.

Martin Marietta has evaluated current and developmental COMSEC equipment and recommends the implementation described in Volume II of this report.

10.0 RELIABILITY, MAINTAINABILITY, AVAILABILITY ANALYSIS (RMA)

10.1 Introduction.

The purpose of this section of the report is to define a range of RMA values for the Flexible Intraconnect (FI) candidate system architecture to be used as baseline requirements for further system definition/development activities.

10.2 Scope.

The analysis covers the FI equipments necessary to form one segment of the FI. Figure 10-1 depicts the portion of the FI analyzed. The remaining segments of the FI are a repeat of the analyzed segment. Figure 1-2, Implementation of Recommended System, shows the configuration evisioned for employment in the C^3 equipment centers. The analysis considers only one of the LIUs in a shelter. In actual implementation as many as 64 LIUs can be used to interface with devices within the shelter. The transponder/EICU can interface with up to 63 shelters. The analysis, however, analyzes only one interconnect between the transponder and a device within a shelter.

The analysis does not include the Special Adapter Unit (SAU). The complexity and design of an SAU will vary from application to application making it unrealistic to identify the design of the SAU until specific using devices are identified.

10.3 Reliability.

The mean-time between failure (MTBF) for the FI hardware was derived from parts lists supplied by project engineering for each of the devices. The failure rates used, with a few exceptions, to be discussed later, were taken from MIL-HNBK-217B Reliability Prediction of Electronic Equipment updated to Notice 2 dated 17 March 1978.

10.3.1 Injection laser. Engineering identified injection lasers for use as a light source for the fiber optics. MIL-HNBK-217B does not have failure-rate data on these devices. To obtain failure-rate data on these devices, a vendor/user survey was performed, but results were not enlightning. No one could or would supply field data on the devices. Several vendors, however, guarantee their devices for 10,000 hours, and some spec sheets list 100,000 hours MTBF. Upon questioning those vendors who claim 100,000 MTBF, it was discovered that this MTBF is arrived at by extrapolating step/stress testing on the device. One point gleaned from conversations with the vendor/users on the injection laser was that the failure mode was due to a loss in output power with time.

To establish a failure rate for the injection lasers, a range of failure rates was established. This range being the reciprocal of the 10,000 hour guaranteed MTBF and the 100,000 hour extrapolated MTBF. In the Summary Table, 10-1, those equipments using injection laser will reflect a range of failure rates. One will have to assume at this point that the true falure rate for the injection laser lies somewhere in the range of 0.000010/hr. and 0.000100/hr. This range of failure rates was used in the analysis.

Table 10-1 RMA SUMMARY

Equipment Item	Failure Rate/ hr x 10-6	MTBF	MTTRi	Availability
LIU	55	18182	1.0	0.999
LICU	103	9708	1.0	0.9998
EIU	163 703	6135 1422	1.5 1.5	0.9997 0.9998
TRANS/EICU	279 819	3584 1221	2.0 2.0	0.999999 0.999996
FI MANAGER	3,933	254	1.66	0.9935
			System Availability	0.9929 0.9921

The vendor/user survey pointed out a lack of testing or field data on the injection laser and a definite need for a test program to determine the reliability of the device and an understanding of the failure characteristics it exhibits.

10.3.2 Bubble memories. Bubble memory is another device that does not have a failure rate covered. The failure rate used for this analysis was derived from a paper presented at "Electro 77" in New York City, N.Y. on April 19-24, 1977 by William C. Mauity, Autonetics Group, Rockwell International, Anaheim, CA. The work efforts in the paper was sponsored by NASA at Langley Research Center, under Contract NASI-14174. This paper gives reliability information from which a failure rate of .0152 x 10^{-6}/hr/bit was derived. This failure rate was used in performing the reliability analysis.

10.4 Redundancy.

The Transponder/EICU in a review of the initial design constituted a FI single-point failure. If one transponder/EICU would become inoperative, the complete C^3 network would become inoperative. Due to this reason, redundant transponders are recommended in the candidate architecture of the FI. The transponder/EICUs should be located in different shelters, with the "T" coupling connections external to the shelters, in the event a complete shelter would be destroyed. The remaining hardware in the FI would cause, in the case of a failure, only partial loss of the complete C^3 system and once inside a shelter, i.e., at the LIU level, the shelter would be operating in a degraded mode until the failure was corrected.

10.5 Methodology.

A typical Reliability analysis worksheet is shown in Table 10-2. The example given is for the LIU. The failure rates used in the example were derived from MIL-HNBK-217B. Notice 2. The parts identified are typical parts that would be used to perform the LIU functions and are not necessarily the actual part numbers in the final design.

10.6 Maintainability.

Several factors were considered in evaluating the mean-time to replace (MTTR) for the FI system. The piece-part count was considered to evaluate the number of circuit boards necessary to make up each unit of the system. Packaging was also considered and was assumed to be rack-mounted chassis with easy accessibility for replacement. All piece parts were assumed to be mounted such that only modular replacement is necessary to correct a malfunction in the unit. Another factor considered was the failure potential of the parts within the system. The similarity of the FI to other equipment designed and evaluated in-house was also used in evaluating the MTTR of the units. For the FI Manager unit MTTR, which is made up of a PDP 11/70 or equivalent computer and peripheral equipment, a RMA study developed for an in-house contract was used.

It was assumed that the diagnostics of the system software are such that in-line software will be available to indicate that a failure has occurred in the system. In conjuction with this software and to further isolate the malfunction, on-line software will be available to identify the problem to a unit within the system. Once the malfunction has been isolated to a unit in the system, it was assumed that off-line software is available to isolate the problem to the replaceable unit.

The MTTR for the FI ranges from 1.0 to 2.0 hrs. Figure 10-1 lists the MTR for the each unit of the FI under consideration. The majority of the MTTR is for isolation of the failure. The actual replacement time should be minimal once the location of failure has been isolated.

TABLE 10-2 LIU RELIABILITY METHODOLOGY

Component Description		Quantity	Failure Rate	Total Failure Rate
AM8T26A	3-State Quad Bus Dr/Rec	5	0.1494	0.747
8T23	Dual-Line Driver	2	0.032481	0.064962
8T24	Triple-Line Receiver	1	0.042479	0.042479
8085A	8-bit___Processor	1	1.80522	1.805223
8259	Programmable Interrupt Cont.	1	0.445038	0.445038
8155	2k Static RAM	40	0.480326	19.21304
8355	16k ROM	4	0.515526	2.022104
34725	16x4 RAM	4	0.04888	0.19552
93524A	1024x1 RAM	72	0.2791	20.0952
54S189	16x4 RAM	18	0.04888	0.87984
54S00	Quad 2-Input And	18	0.027811	0.500598
54S04	Hex Inverter	18	0.032481	0.584658
54S20	Dual 4-Input Nand	8	0.016471	0.131768
54S65	4-2-3-2 Input And-or-Invert	6	0.032481	0.194886
54S74	Dual F/F	12	0.042629	0.511548
54S85	4-bit Map Comp.	9	0.06538	0.58842
54S112	Dual JK F/F	10	0.049628	0.49628
54S116	Dual 4-bit Latch	6	0.06004	0.36024
54S163	4-bit Sync Counter	6	0.07139	0.42834
54S374	Parallel-in Parallel-Out	4	0.07072	0.28288
54S113	3 5-Dual Diff Line Dr.	20	0.049628	0.99256
25S2521	8-bit Comparator	4	0.06004	0.24016
93434	ROM (32x8)	2	0.034054	0.068108
340174	Hex D F/F	2	0.06605	0.1321
9615	Dual Differ Line Dr.	20	0.027811	0.55622
54S260	Dual Five Input Pos Nor	4	0.021407	0.085628
LM123	5 Volt Reg	4	0.064221	0.256884
LM126	12 Volt Reg	2	0.0907	0.1814
Capacitors	(Tant)	20	0.00448	0.0896
Capacitors	(Cer)	200	0.0048	0.96
Resistors		40	0.00748	0.2992
34520	Dual 4-bit Binary Ctr	2	0.06605	0.1321
T105C05E	2.5 25 MH Osc	1	0.408	0.408
Connectors	40 pin	1	0.4032	0.4032
	30 pin	1	0.4651	0.4651
			$\lambda LIU \Sigma$	54.460284

$$MTBF = \frac{1}{\lambda LIU} = \frac{1}{55} = 18,182$$

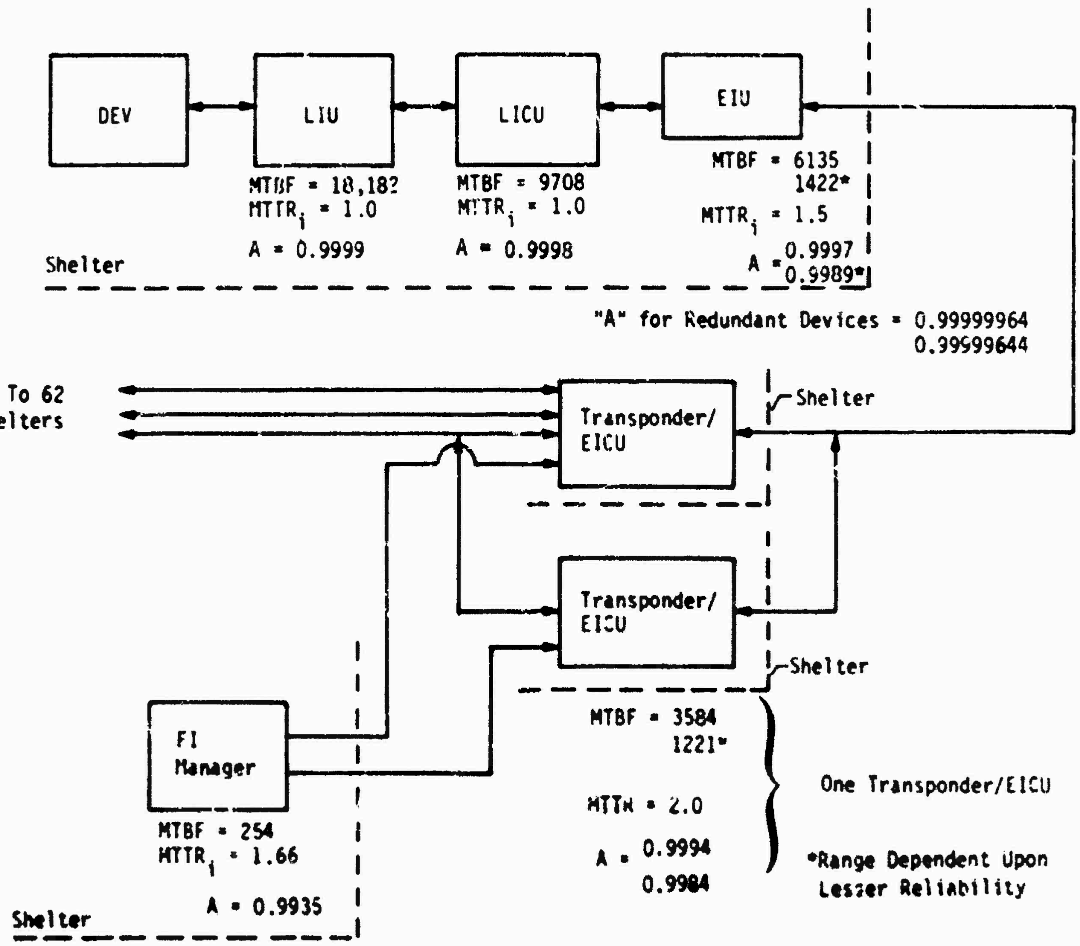


Figure 10-1. RMA block diagram.

10.7 Availability

In evaluating system design concepts, reliability and maintainability analyses are the prime evaluation factors in determining item contribution to system avalability. At the hardware item level of availabilty evaluation, the following relationship was used:

$$A_i = \frac{MTBF}{MTBF-MTTR}$$

where:

A_i = Inherent Availability
MTBF = Mean-Time-Between Failure
$MTTR_i$ = Mean-Time-To-Replace (Inherent)

The preceding two sections have discussed the source of the reliability values (failure rates and MTBFs) and maintainability (MTTR), used in calculating item availability.

Availability for the redundant transponder was determined by the following equation:

$$A_{RE} = 1-(1-A_1)(1-A_2)$$

where:

A_{RE} = Availability for the redundant element
A1 A2 = Availability of a single element

Thus:

The availability for the redundant transponder/EICU is:

$$\begin{aligned} A_{RE} &= 1-(1-0.9994)(1-0.9994) \\ &= 1-(0.0006)(0.0006) \\ &= 1-0.00000036 \\ &= 0.99999964 \end{aligned}$$

From Table 10-1, the system availability is:

$$A_{sys} = A_{LIU} \quad A_{LICU} \quad A_{EIU} \quad A_{Trans/EICU} \quad A_{F}Manager$$

10.8 Summary.

Table 10-1, the RMA summary, is a culmination of data for the FI devices analyzed. It identifies a range of system availability numbers created by the range of failure rates identified for injection lasers. The range of the system availability numbers for normal and worse-case laser reliability are not sufficiently different (0.9929 and 0.9921) and give a range on availability. The availability requirement for the single element of the FI is 0.99.

10.9 Conclusions.

To obtain a FI availability requirement for the C3 system, the following steps should be followed:

a. Determine the number of LIUs in each shelter to arrive at the availablity of the shelters.

$$A_s = A_{LIU} \quad A_{LICU} \quad A_{EIU}$$

where

A_s = Availability for the shelter
A_{LIU} = Availability for LIU
n = Number of LIUs in the shelter
A_{LICU} = Availability of LICU
A_{EIU} = Availability of EIU

b. Determine the availability of all shelters in the C^3 systems.

$$A_{C3_s} = A_{s1} \quad A_{s2} \quad \ldots . A_{sn}$$

where

A_{C3S} = Availability all C^3 shelters
A_{s1} = Availability of shelter #1
A_{s2} = Availability of shelter #2
A_{sn} = Availability of nth shelter up to 63.

c. The last step derives the availability of the FI for a given C^3 system.

$$A_{C3sys} = A_{C3_s} \quad A_{T/EICU} \quad A_{FI\ Mgr.}$$

where

A_{C3sys} = Availability of FI for C^3 system
A_{C3_s} = Availability of all shelters in the C^3 system
$A_{T/EICU}$ = Availability of transponder/EICU
$A_{FI\ Mgr.}$ = Availability of the FI Manager

With Availability numbers identified to the level that appears in Table 10-1, the FI availability of any configuration of C^3 System can be identified from the above steps.

CONTENTS

APPENDIX A

LIST OF ILLUSTRATIONS

1.0 APPENDIX A

1.1 Communication integration into the FI.

1.1.1 Introduction. The Flexible Intraconnect (FI) will be used in conjunction with a circuit switch and a technical control facility. These units are located in separate shelters and perform switching, multiplexing, and supervisory functions for telephone users in Air Force operating centers. Refer to Modular C^3 Interface Analysis, Task I OR 15,042, for deployment configurations. The circuit switch and tech control are in a serial path from the user to the transmission device for loop to trunk calls or those routed outside the center. For loop-to-loop calls, only the users and circuit switches are involved.

Since the FI is a type of packet switch, an additional capability for switching, multiplexing, transmission, and supervisory control is introduced into the system. It is the purpose of this part of the study to introduce a concept of integration of the packet switching functions performed on the FI with those now done conventionally in other units and eliminate their redundancy. This new capability offers redundant functions to those now performed in the circuit switch and tech control. The concept is evolutionary, assuming a gradual introduction into the system.

1.1.2 System functions. Call routing and supervisory signaling: In the present-day system, calls in a typical AF operating center, such as TACC, can be analyzed in two groups: Intracenter, or loop-loop calls, and inter-center, or loop-trunk calls (Figs. 5-49 and 5-50). Calls are first set up by a supervisory signaling interchange between the calling instrument, the call processor (CP) in the circuit switch, such as the AN/TTC-39, and the called instrument. In the case of trunk calls, an additional supervisory signaling interchange is necessary between the local switch and the distant switch before the call connection is made. When the initial supervisory signaling has been completed, the call is made through the switching matrix in the circuit switch. When trunk calls are necessary, the routing function in the switch is brought into play and trunk groups are formed for transmission to the distant switch. Transmission groups are formed from trunk groups in the tech control facility (CNCE). The channel reassignment function (CRF) in the CNCE is a time-division switch that organizes trunk groups into transmission groups destined for various other switches. The CRF is under the direction of a processor in the CNCE. In addition to these functions, network control functions need be considered. The network controllers in the CNCE (and CSCE) require reports of traffic statistics from the switch and send directives to the switch for control of traffic loads and other network sensitive functions. These directives and reports are passed between switch and CNCE over dedicated 2kb/s or 4kb/s control channels. Network control must be exercised regardless of the configuration of the communication network and, therefore, must be accounted for in all phases of FI application.

1.1.3 FI phases and integration concepts. For purposes of investigating the FI integration concepts, the FI can be considered in four evolutionary phases. The integration of FI and switching function is incorporated into phases III and IV.

1.1.3.1 Phase I, static polling. In the static polling phase, all devices using the FI are permanently assigned a block for transmission of data whether or not there is data to be sent. Dedicated circuits are permanently addressed to their destination and switched circuits are permanently addressed to a particular circuit at the switch. In Phase I, there is no integration of FI, circuit switch, and CNCE functions. Phase I was considered as an alternative in Task I because it was the simplest implementation of the FI. Phase I has since been disregarded as a viable implementation. Phase II will probably be the first implementation concept.

1.1.3.2 Phase II, adaptive polling. Phase II introduces adaptive polling wherein devices are not assigned message space on the FI unless they have traffic. Dedicated circuits are addressed to their destination and switched circuits are addressed to the switch but neither are assigned space on the FI until they have traffic. In both Phase I and Phase II, all call processing, except LI intercom processing, is done in the circuit switch and not on the FI.

1.1.3.3 Phase III, adaptive polling, call processing of loop-loop calls on FI: In Phase III, call processing functions required for loop-loop calls are integrated into the FI. Only that call processing required for trunk calls is performed by the circuit switch.

1.1.3.4 Phase IV, distributed switching of switch and CNCE functions on the FI (the concept of circuit translation). In Phase IV, all call processing is performed in the switch, but there is an interaction with the FI for performing address translation so that after call processing functions have been performed, messages or calls may be addressed directly to their destination, thereby bypassing most switch and CNCE switching matrices multiplexing, and modern functions.

Phases III and IV are the integration concepts to be studied. Phase II will be used for a comparative evaluation.

1.1.4 Rationale for determining call processing requirements. In Phase III, it was proposed that all loop-loop call processing could be performed on the FI, and trunk call processing would be retained by the circuit switch. This arbitrary decision was made to minimize FI complexity. It was determined that the complexity of including any of the switch-routing functions, such as alternate routing tables, zone restrictions, and switch-to-switch signaling requirements would not be warranted due to their complexity.

To establish more exactly what call processing requirements were applicable to FI integration, an investigation of the AN/TTC-39 and AN/TTC-42 specifications was made and all the loop-loop oriented call processing functions were itemized. These are contained in Appendix B entitled "Flexible Intraconnect Call Processor Requirements for Phase III Implementation." Also included in this document are those network control functions necessarily included on the FI with the assumption of loop-loop call processing functions on the FI. It should be recognized that with the incorporation of the switching functions on the FI, it will be necessary for the network controller to gather traffic statistics from the FI and impose traffic load control. This means the FI must then be able to issue TCCF reports to the network controller and receive TCCF directives. This document is intended to be a top-level summary, written in specification format, of requirements that would be imposed on the FI were it to assume these call processing functions of the switch and technical control facility.

1.1.5 Integration concepts:

1.1.5.1 Phase II. In the Phase II FI, both supervisory signaling and the actual calls are handled in the body of the message as textual data. As in Phase I, the switch call processor sets up each call and all calls are routed through the switch matrix to their destination. Figure 5-51 shows the paths taken by each in loop-loop calls. Figure 5-52 shows the routes taken by interswitch or trunk calls. Note: With trunk calls, routing functions and trunk group functions come into play in the switch, and the transmission group function comes into play in the CNCE. Note further that the single loop-trunk call has traversed the FI three different times to get to its destination, the radio.

1.1.5.2 Phase III. In Phase III, all loop-loop call processor functions would be included on the FI. The call processor functions may be either distributed in SAUs LIUs, or LICUs or centralized in or near the EICU. For purposes of this discussion, a centralized FI call processor will be assumed. The call processor will provide all loop functions now done in the AN/TTC-39 or AN/TTC-42, and all associated control functions, i.e., all functions contained in Appendix B. In addition, the CP will provide a memory to track the busy status of FI telephone users. This is to avoid the necessity for ACK-NAK in communication transfers on the FI.

Figure A-1 shows the supervisory signaling and call routing of a loop-loop call. Supervisory signaling is set up between the originator of the call and the CI CP. From its status memory the CP determines that the destination is not busy and transfers the destination address to the originator. The originator then addresses the destination directly and maintains the call with the destination. The CP monitors the progress of the call and maintains cognizance at all times for possible priority interrupts, termination of calls, and other required functions. System control functions, such as report transmittal and directive processing are performed directly from the call processor unit to the CNCE.

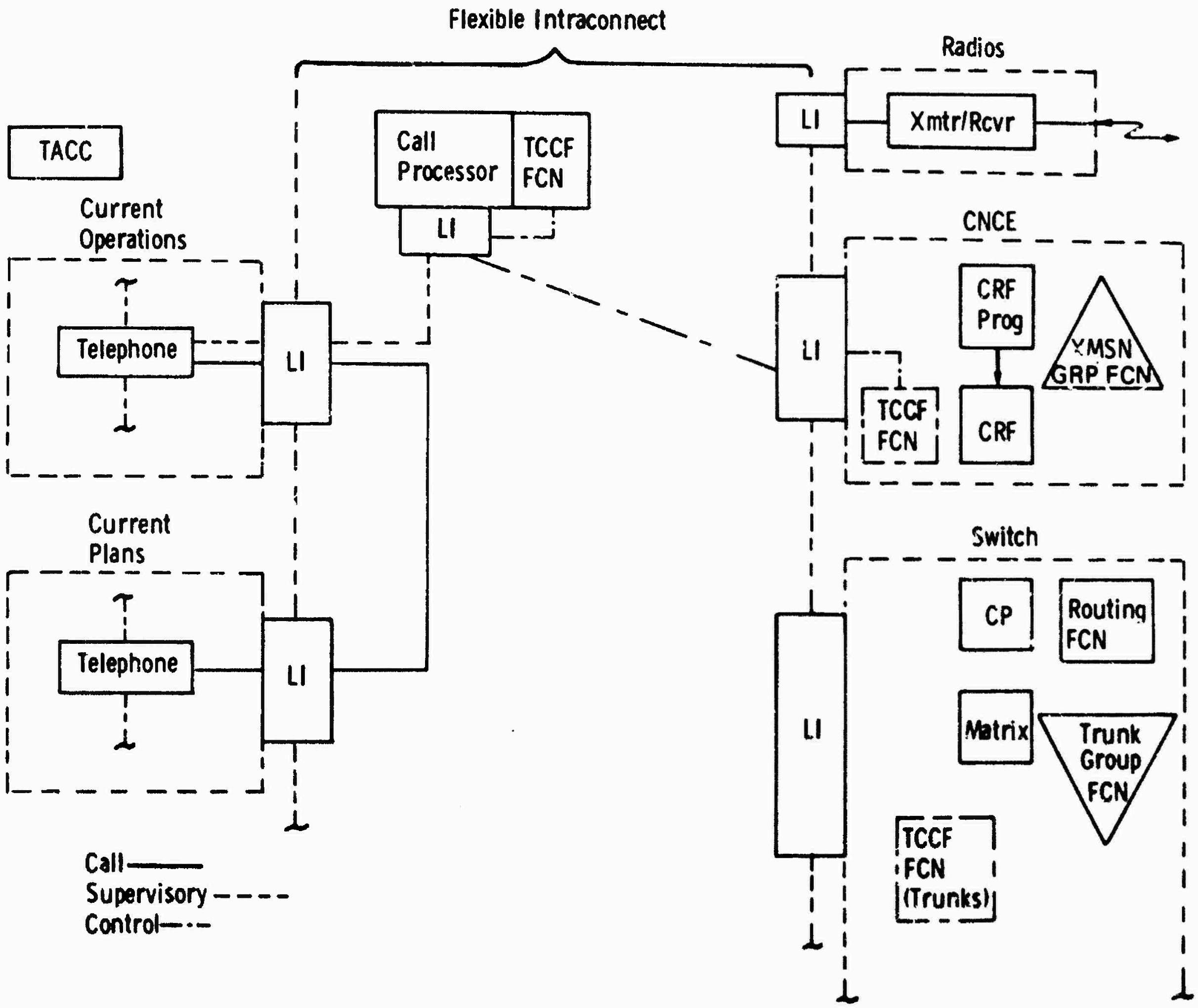


Figure A-1. Call processor/FI integration concepts integrated (loops) CP/FI/TCCF intracenter call (loop-loop).

The feature of this method is that local calls may be directly addressed from originator to destination so calls are routed over only one path on the FI. FI complexity is, of course, increased by the addition of the CP, and switch complexity is correspondingly decreased.

In Phase III, the method of handling trunk calls is not changed from Phase II.

1.1.5.3 Phase IV. The problem with the Phase III method is the burden placed on the FI of assuming supervisory signaling functions of the call processor. Because of its packet switching nature, the FI performs switching, transmission, and multiplexing functions more readily than it does the call processing functions associated with them. Therefore, a logical alternative to integrating the call processor on the FI is to integrate only switching and multiplexing and modem functions, and leave the CP functions with the switch.

But to do this, it is necessary to provide a more direct interchange of information between the FI and switch CP. This is done by adding an address translation function either to the CP, or to the FI. In this method, matrix switching of the call, trunk group multiplexing, channel reassignment (trunk group switching), and transmission group multiplexing are distributed on the FI. These are functions which were originally done in the circuit switch and CNCE. In Phase IV, both loop-loop calls and trunking are affected.

In Phase IV, an address translator would be added either to the FI or to the call processor of the circuit switch (AN/TTC-39 or AN/TTC-42) and to the CRF in the CNCE. The function of the address translator would be to allow the CP to inform the FI of the destination address in terms of FI addresses. This allows the CP to accept calls from the originator over the FI and to inform the originator of the new destination address. This feature is the essence of the Phase IV method. The method is best described by the following examples:

1.1.5.3.1 Loop-loop calls: (Fig. A-2). The originating telephone directs its call to the switch call processor in the usual manner. The switch call processor sets up the call with the destination telephone in the usual

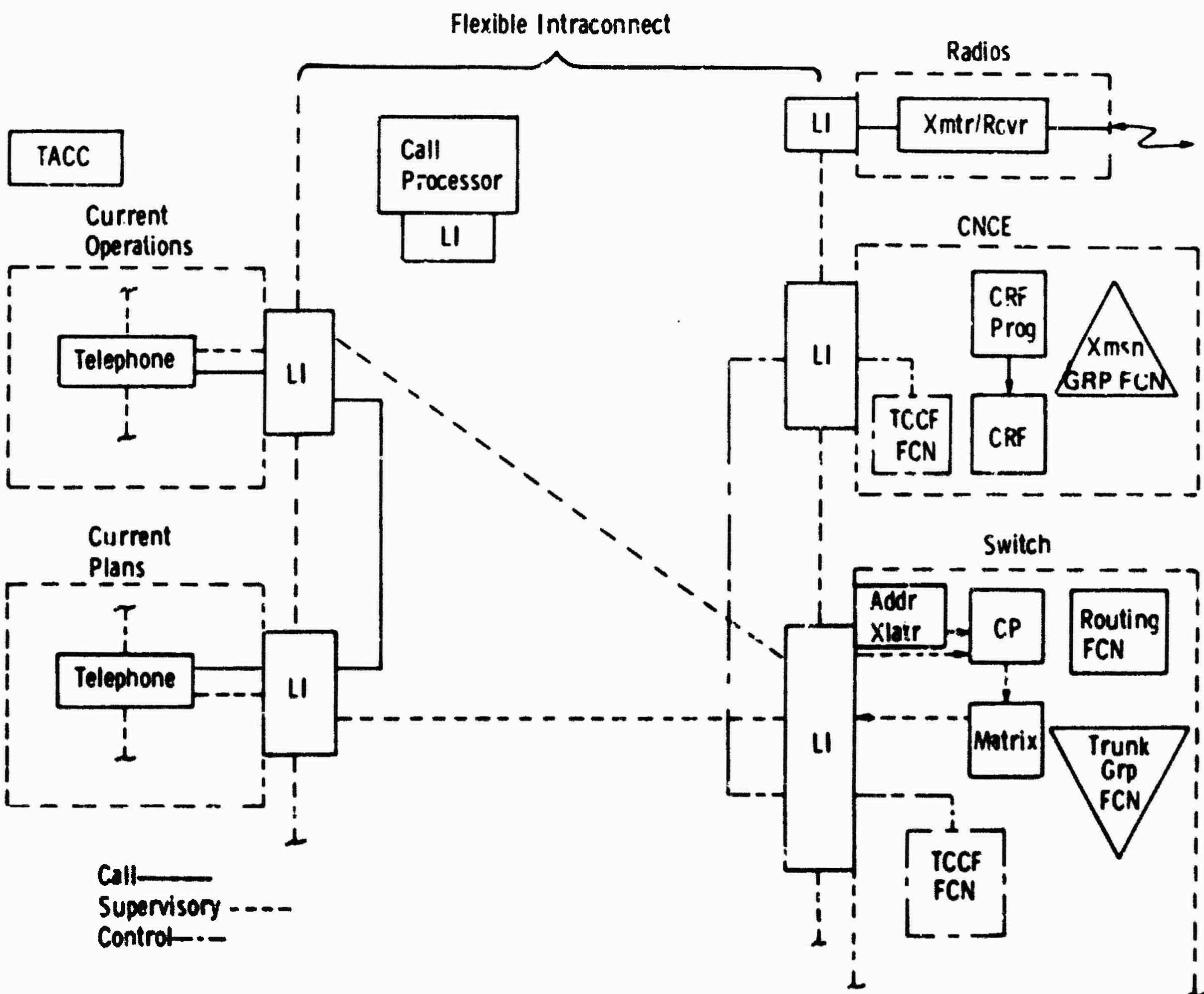


Figure A-2. Call processor/FI integration concepts CP/FI/TCCF separated, interacting intracenter call (loop-loop).

manner by providing the necessary supervisory signaling. When the call is ready to be connected, the switch CP informs the originating LI of the FI address of the destination LI through the address translator. The originating LI then inserts the destination address into the message and the call takes place directly from the originating LI to the destination LI without using the circuit switch matrix. Since all stations have access to the data, the CP monitors the progress of the call and exercises any necessary break-in or termination procedures.

1.1.5.3.2 Trunking. It is the loop-trunk calls and trunking that demonstrate the most dramatic advantage of the Phase IV concept (Fig. A-3). The sequence in making a loop-trunk call is as follows:

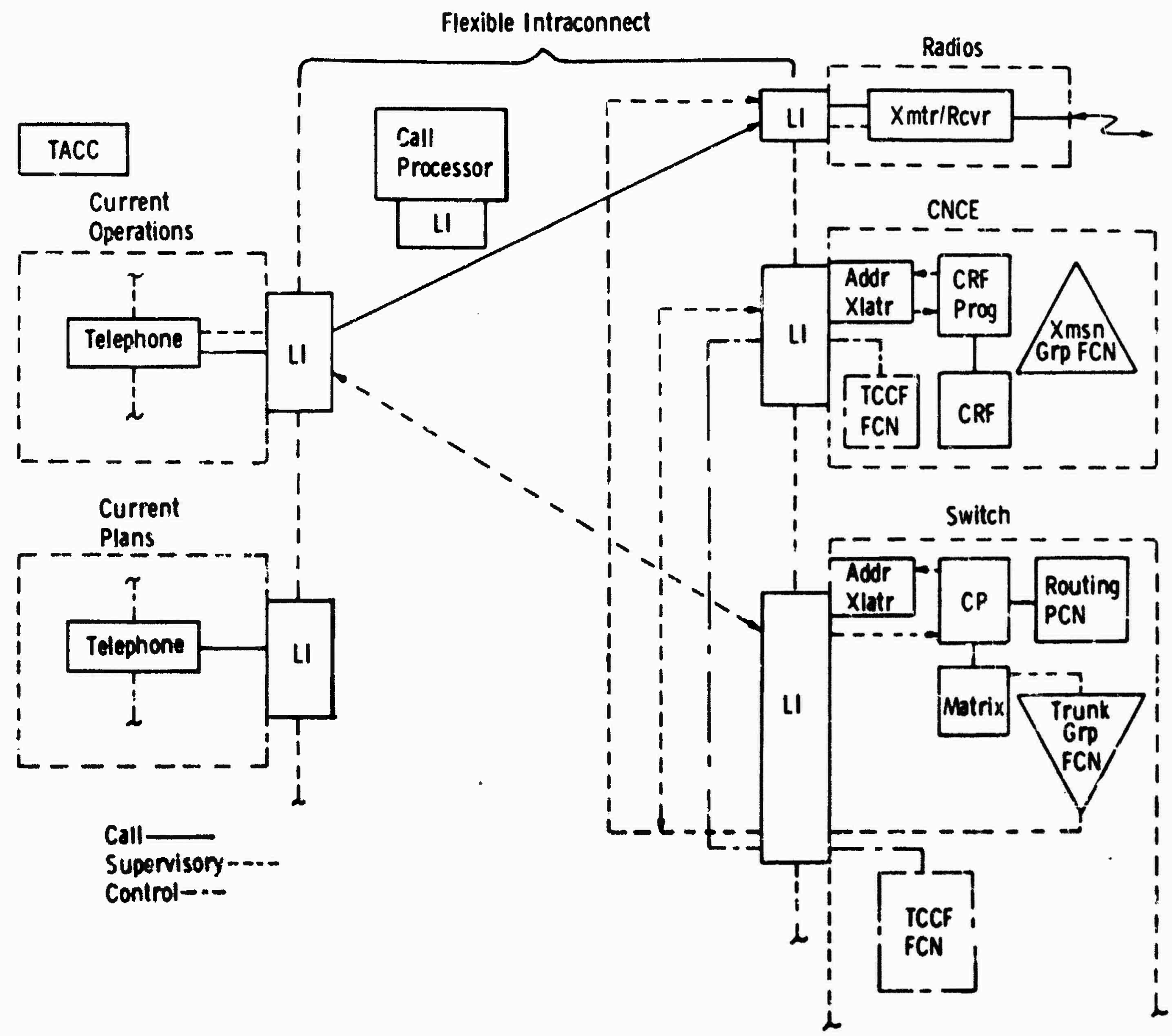


Figure A-3. Call processor/FI integration concepts CP/FI/TCCF separated, interacting intercenter calls (trunks).

a. The originating telephone addresses the switch call processor as before.
b. Since the call is to go out to a distand switch, the CP consults the routing function and initiates supervisory signaling with the distant switch over a trunk group supervisory signaling channel. The signaling uses the switch matrix and the switch trunk group function to address the CNCE CRF.
c. The CNCE CRF address translator informs the switch CP of the destination address at the transmitter.
d. The switch CP then transmits its supervisory signaling messages directly to the LI at the transmitter/receiver bypassing the CNCE.
e. When the supervisory signaling process is complete with both the distant and the originating telephone, the call connection is ready to be made.
f. At this point, the switch call processor knows the address of the destination LIU at the transmitter receiver and informs the originating LIU of its address.
g. The originating LIU then transmits the call directly to the radio LIU bypassing the switching matrix and trunk group multiplexing functions in the circuit switch, and the CRF and transmission group function in the CNCE.

Note: Neither the switch nor the CNCE relinquish any control of the signal path to the FI. Both switch and CNCE maintain positive control of the destination of the signal as in conventional methods. It is only the path of the signal that bypasses both units.

In the above discussion, one important function was omitted for clarity. That is the formation of trunk groups in the switch and transmission groups in the CNCE. The call must be a part of a trunk group when it leaves the switch and that trunk group must be a part of a transmission group when it leaves the CNCE. In the formation of a trunk group or of a transmission group, the telephone channel can be completely described by an address. These addresses are in fact used in forming the multiplexes in the trunk group function and transmission group function and, therefore, are available from the switch and CNCE for use on the FI. The destination address, which the CP eventually sends the originating LI, can then contain the address description of the destination trunk group and transmission group. In this way, the multiplex is formulated at its destination LI, i.e., in the radio, and can be transmitted through the transmission system in its customary form; a serial TDM signal.

The main advantage of this system is the reduction in the number of times the signal must traverse the bus from three to one, with additional advantages of eliminating the switching matrix and trunk group functions from the switch and the CRF and transmission group functions from the CNCE. (However, some of that capability would be required for supervisory signaling). Also, there is an additional advantage. There would be no need for the transmission devices in the CNCE and switch, i.e., modems, and COMSEC equipment would not be necessary for loop and trunk traffic.

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APPENDIX B

LIST OF TABLES

NOTE: This appendix is a summary of those requirements which would be imposed on the FI if it were to assume the call processing functions of the switch, with its associated network control functions, and the transmission group switching functions of the CRF in the CNCE. Entries were taken, in part, from the AN/TTC-39 (circuit switch), AN/TTC-42 (ULS), AN/TSQ-111 (CNCE), and AN/TYQ-16 (CSCE) specifications. The appendix is intended to provide the necessary detail to make comparative evaluations between Phase II, III, and IV concepts in this study.

APPENDIX B

Flexible Intraconnect (FI) Call Processor (CP)
Requirements For Phase III Implementation

1.0 GENERAL

In the Phase III implementation of the FI, certain circuit switching and technical control functions are integrated with FI functions. This generates the requirement for a call processor function on the FI that was formerly performed in the circuit switch. The requirements for that call processing function integrated with the FI is defined here. The FI call processor will service all local loops that terminate on the FI within a tactical Air Force operating center. The assumption is made that all calls directed out of the center will be routed from the FI CP to a circuit switch for disposition. Those technical control functions which are to be integrated with the FI will be listed separately from the call processor.

2.0 CALL PROCESSOR REQUIREMENTS

2.1 Signaling and Supervision.

All subscriber lines shall employ the signaling and supervision technique compatible with the end instrument terminated thereon. The signaling and supervision techniques for these end instruments is described in Paragraph 3.1.2.3 of TT-B1-1101-00014 and TT-A3-9002-0017.

2.1.1 Information signals. The CP shall be capable of generating and transmitting to subscribers and trunks a series of audible tone signals or recorded announcements which shall be used to inform the subscriber of the progress or disposition of a call. The characteristics of those tone signals to be used which are not presented in or are different from MIL-STD-188-100 shall be as specified in Table B-1. In addition, distinctive line-busy and trunk-busy tones shall be provided.

2.1.2 Circuit switch service. In addition to the basic service of establishing connections between subscribers on a direct dialing basis, the CP shall be capable of providing circuit switching services through modular hardware and software implementation as specified herein. Those services having a special access signal will not be offered to telephone instruments incapable of exercising them, e.g., the signaling of a precedence indicator from a dial-pulse telephone.

2.1.2.1 Precedence and preemption. Circuit-switched subscribers on the FI shall be capable of establishing local, interswitch, and extra-switch calls (with precedence compatible switches) using a five-level precedence and preemption service. When a call (any type) is established, all connections shall be maintained at the precedence level assigned by the originator of the call regardless of the precedence level authorized to other participants in the connection.

TABLE B-1. AUXILIARY INFORMATION SIGNALS

Signal	Frequencies (Hz)	Level ±1dBm (at a -4dBr TLP)
Conference notification tone	350/620(mixed)	-14
Broadcast conference notification tone	500	-14
Lock-out tone	350/480(mixed)	- 7
Conference disconnect tone	480/620(mixed)	-14
Nonsecure warning tone	1050	-24
Call transfer dial tone	1050	-14

The interrupt rates for the above tones shall be as follows:

Signal	Rate	Tone on (sec)	Tone off
Conference notification tone	Burst	1.0	---
Broadcast conference notification tone	Burst	1.0	---
Lock-out tone	Continuous	---	---
Conference disconnect tone	Burst	1.0	---
Nonsecure warning tone	20 IPM	0.5	2.5
Call transfer dial tone	Continuous	---	---

Intercept tone (recorded announcement)

The five levels, in order of descending precedence, shall be FLASH OVERRIDE (FO), FLASH (F), IMMEDIATE (I), PRIORITY (P), and (ROUTINE) (R).

Through class of service marks, it shall be possible to assign any procedence level as the maximum authorized pecedence for a subscriber line. The assignment shall be readily alterable on-line from the SSF.

2.1.2.2 Conferencing. The FI CP shall be capable of providing three types of conference service: Progressive, preprogrammed, and broadcast. Conference privileges shall be assigned to subscribers through classmark service that shall be software programmed (class-of-service marks) and readily alterable. The conference capability for switches shall be six conferences of five parties each per 750 terminations or less.

2.1.2.2.1 Progressive conference. A progressive conference shall be based on the technique whereby the subscriber or attendant calls each conferee in sequence, waiting and verifying the success or failure of connecting the called conferee into the conference before calling the next one.

The conference originator shall have complete control of the conference at all times. By rekeying the conference key, the conference originator shall be able to cancel a call to a potential conferee before the called line is answered or in case the called line is busy. He shall be able to add new conferees, after the previously called conferee has answered or is released, by keying the conference key followed by the address of the desired conferee.

A progressive conference shall be capable of handling up to 19 conferees plus the originator.

2.1.2.2.2 Preprogrammed conference. A preprogrammed conference shall be based upon establishment of a conference from a software programmable list of predesignated subscriber conferees. The conference may contain conferees who are local subscribers to the switch, and also conferees who are subscribers to remote switches and therefore may be accessed via the remote switch's conference bridges.

For a 750 termination FI, the switch program shall be capable of storing a minimum of 20 preprogrammed conference groups. The conference grouping capability for other switch sizes shall be linearly proportinal. A preprogrammed conference group at any switch shall be capable of handling up to a maximum of 19 conferees plus the originator, and may be capable of being combined with other preprogrammed conference groups at either the local or distant switches to form a larger conference.

2.1.2.2.3 Broadcast (announcement) conference. The broadcast conference shall be based on the technique described for progressive and preprogrammed conferences. The broadcast feature shall be capable of serving up to 30 conferees including the originator.

2.1.2.3 Call transfer. The CP shall provide call transfer service to circuit switched subscribers assigned this privilige.

Any one of the subscribers on a circuit switch or the CSF attendant shall be capable of having his directory number transferred to another directory number. However, the maximum number of simultaneously transferred subscribers per 750 termination circuit switch shall be 40. The capability for other circuit switches shall be linearly proportinal.

The subscriber shall be capable of initiating this service from his telephone instrument by first dialing a special access code and then dialing the directory number to which he desires his calls to be transferred. The telephone instrument shall still provide the capability to place outward calls while in the call transfer condition. When a subscriber line is in the call transfer condition the circuit switch will send a unique dial tone to the telephone.

2.1.2.4 Compressed and abbreviated dialing. The CP shall be capable of providing compressed and abbreviated dialing to subscribers.

2.1.2.4.1 Abbreviated dialing. The FI CP shall provide abbreviated dialing on a switch-wide optional basis. The abbreviated dialing feature shall allow the CP to complete local calls when any subscriber dials only the last three or four digits of the called party's seven-digit number.

2.1.2.4.2 Compressed dialing. The CP shall provide Compressed Dialing. The subscribers so designated may dial a two-digit number plus "end-of-dial" (EOD) to reach another subscriber. The CP shall translate the two-digit code and route the call to the called party. Compressed dialing shall be provided in two categories: Common-pool compressed dialing and individual compressed dialing.

a. Common pool-compressed dial service. The 750 termination FI shall have the capability for a maximum of five common pool directories, each directory capable of containing a maximum of 80 two-digit dial codes. Subscribers authorized common-pool access would be class-marked according to a particular common-pool directory, and a subscriber authorized access to one directory will have access to all the codes within that directory, but would be denied access to any other directories.

b. Individual compressed dial. In addition to the common-pool capability, the FI shall also provide one additional directory of 80 codes, each to be used on an individual basis, i.e., those subscribers that are class-marked for access to this particular directory can be further class-marked for access to specific individual entries in the directory. As indicated, access to this individual compressed dial directory will be restricted to those subscribers appropriately class-marked. A subscriber with access to this directory will not have access to any common-pool directories.

2.1.2.5 Call forwarding. A subscriber may forward an incoming call that he has received, to another subscriber of his selection by use of the Attendant Recall feature (see Paragraph 2.1.2.9).

2.1.2.6 Secure call code/key conversion. The circuit switch shall provide for secure call mode and key conversion for properly class-marked loops and trunks terminated on the SDMX for secure calls between incompatible voice security equipment.

Initial signaling by loops and trunks employing the feature shall be transmitted and processed in the clear. The circuit switch shall determine from the class-marks the requirement to institute a mode or key conversion.

2.1.2.7 Automatic line grouping. The circuit switch shall provide automatic idle-line hunting service for properly class-marked circuit switch subscribers. Up to 32 individual hunting groups shall be provided. Each group shall be capable of accepting from two to five subscriber lines. The features provided by this service shall be as follows:

a. The subscriber addresses in a hunting group need not be arranged in an orderly numerical sequence.

b. Hunting for an idle line in the group will occur whenever the called number in a group is busy.

c. In the event all lines in a group are busy the calling party shall be returned a line busy tone.

c. When a preemptive call experiences an "all lines busy" condition within the called group and the calling precedence is higher than at least one of the busy lines, the lowest precedence busy line shall be preempted and the higher precedence called connected to it.

2.1.2.8 Direct-access service. The CP shall provide Direct Access Service (DAS) to 10 percent or 40 of the available lines (whichever is greater), via the switched communications network.

DAS imitates sole-user service, i.e., if subscriber A goes off-hook, the circuit switch shall immediately establish a connection to subscriber B. Subscriber A may only accept calls from subscriber B. These conditions also hold in reverse for subscriber B.

2.1.2.9 Attendant recall. It shall be possible for a subscriber to call or recall the Call Service Function (CSF) attendant. To initiate a call to the attendant, the subscriber would enter the precedence of the call, if any, and then the digit "0". To recall the CSF attendant while a call is in progress, either subscriber may enter the digit "0". The precedence of a recall is the same as the precedence of the call in progress. The call or recall request shall be stored in the appropriate precedence queue at the CSF. The CSF attendant shall be able to extend either or both parties of a recalling connection to any other termination to which they may be authorized access. The CSF attendant may make these extensions at any precedence level. Either recalling party may release himself from the connection without releasing the connection between the CSF attendant and the remaining recalling party.

2.1.2.10 Data service. The CP shall provide real-time switching for data subscribers. Subscribers shall operate in accordance with TT-A3-4002-0015 and TT-A3-9002-0017 as applicable. Data services shall be provided for terminals operating with:

a. AUTOVON signaling and supervision;
b. Digitial loop signaling; and
c. TA-341 signaling and supervision

The CP shall be capable of routing connections for circuit-switched data subscribers over circuit trunks to other switching centers and over intra-switch trunks to the S&F Module for S&F service.

2.1.2.11 Class-of-service marks. The CP shall supply call service privileges and exercise restrictions to subscribers through the use of stored program class-of-service marks. These shall be easily alterable by the switch attendant (SSF). The CP shall be capable of processing class-of-service marks as required to satisfy this specification and shall provide for up to 100 unique services. Any number of these class-marks may be assigned in any combination to all subscribers on an individual basis. As a minimum, these shall include:

a. Maximum level of precedence
b. Progressive conference privilege
c. Preprogrammed conference privilege
d. Broadcast conference privilege
e. Call restriction to preprogrammed conference only
f. Subscriber instrument classification
g. Trunk signaling classification
h. Restriction on subscriber dialing access
i. Direct access service (hot-line)
j. Less essential subscribers for traffic load control
k. Automatic line group hunting
l. Compressed dialing privilege
m. Call transfer privilege
n. Secure call privilege
o. Security level
p. Data service
q. Data equipment type
r. Spill forward.

2.1.2.11.1 Intercept. An intercept feature shall be included in the CP that shall provide for the return of a recorded announcement (see Table B-1) to the calling voice subscriber when the number dialed does not exist, is unassigned, or is marked disabled.

2.1.2.12 Zone restriction. The CP shall provide the capability to prevent any subscriber access line or any PBX trunk from completing calls to designated destinations.

A calling subscriber or PBX may be restricted from accessing any combination of the following: Area codes, switching center codes, conference codes. This zone restriction shall be accomplished in the originating switching center and zone restriction assignments in any one switching center shall be independent of the zone restriction assignments in any other switching center.

3.0 NUMBERING PLAN

3.1 Fixed directory codes.

A fixed directory list shall be provided to assist in locating roving subscribers, and a similar list shall be provided to assist in locating roving units. The Fixed Directory Subscriber List (FDSL) shall initially consist of 200 entries, expandable to 3400, indexed by a five-digit code, and shall identify a fixed subscriber number and memory location to direct the call to an outgoing trunk or to a local terminal.

The Fixed Directory Unit List (FDUL) shall consist of 100 entries and shall identify a fixed unit number and memory location to direct the call to an outgoing trunk or indicate the code as a home code.

3.2 Fixed directory translator table.

A directory translator table shall be provided for translating fixed directory codes into routing information to roving subscribers and units. Initial storage of 300 fixed codes and associated routes shall be provided, with modular expansion in segments of 400 such codes up to a total capacity of 3500 codes and routes. Fixed Directory information shall be alterable at each switch from the console of the switch supervisor function (SSF) at the same switch.

4.0 TRAFFIC LOAD CONTROL

The CP shall include programming, whereby the traffic offered to trunks by subscribers can be controlled during peak busy loads. This shall be accomplished in two stages: (1) By restricting less-essential subscribers access to trunks, and (2) by restricting less-essential subscribers from initialing calls.

Traffic load control initiation shall be initiated automatically by the circuit switch as the traffic reaches preset levels, or it may also be initialed manually from the SSF. The preset traffic levels shall be capable of being introduced and changed from the SSF through readily alterable software programming.

4.1 Subscriber levels.

The CP shall provide five levels of traffic load control. Each directly connected subscriber shall be assigned to only one level of traffic load control.

4.2 Traffic level thresholds.

The circuit switch shall implement traffic load control automatically when present thresholds are exceeded by the traffic load during a measured period of time. The time periods shall be variable between one and fifteen minutes in increments of one minute. The circuit switch shall provide the capability for altering the time period from SSF. The CP shall provide traffic metering capabilities which shall bereset to zero at the end of each time period.

Switch access restriction shall be applied when the cumulative number of calls originated by subscribers exceeds preset thresholds.

4.3 Traffic metering.

The CP shall include the capability measure and record the following traffic events:

a. Total number of originated loop calls (precedence and routine);
b. Number of calls offered per trunk group (precedence and routine);
c. Number of ATB situations encountered per trunk group; and
d. Number of calls preempted per trunk group.

4.4 Control subsystem response to TCCF directives.

The control subsystem shall, in general, automatically execute TCCF directives. When the supervisor/maintainer position is manned and the accpet/override feature is activated, the control subsystem shall display the TCCF directive to the supervisor/maintainer and shall execute the directive when so indicated by the supervisor/maintainer.

5.0 TIME-OUTS

The CP shall provide a series of readily alterable time-out functions. These time-outs shall be selectable by traffic supervision and adjustable from 0 to 5 minutes in one second increments. These shall include, but not be limited to, those described in the subsequent paragraphs.

5.1 Common control functions.

A time-out capability shall be provided whereby any portion of the common control shall release itself from performing further functions when the assigned time limits for each functions are exceeded.

5.2 Line circuit time out.

A time-out capability shall be provided whereby a line circuit shall be placed in a lock-out condition when a subscriber exceeds set time limits for dialing a call. These limits shall include:

a. Time limit after receipt of dial tone until first digit is received;
b. Time limit between digits;
c. Time limit between call disconnect and subscriber on-hook; and
d. Time limit after preemption and on-hook condition.

This table itemizes those network control functions which are affected by the integration of the switch CP with the FI as indicated in the proposed Phase III implementation. Since some network control functions interact with more than one network element the "S" and "I" entries denote which element is affected by going from the Phase II concept to Phase III.

6.0 SUMMARY OF SWITCHING AND TECH CONTROL FUNCTIONS FI PHASE II VS PHASE III

Function	FI INT (Phase III)	Interacting Elements (Phase II)
Call Processing & SPVSR Signaling		
Loop	I	Device - Switch
Intercenter Trunks	S	Switch - Switch
Intracenter Trunks	I	Switch - Switch
Matrix Switching	I	Switch
Traffic Status Reporting		
Call Statistics		
Calls Blocked Dial-Tone Delays Total Calls Preempts	I S	Switch - CNCE CNCE - CSCE
Trunk Statistics		
Trunks Busy Calls Preempted Trunk LOS Trunk GR Out	S S I	Switch - CNCE CNCE - CSCE SW(1) - SW(n) - CNCE
Traffic Status		
Routing Classmarks Load-Control Level Zone Restriction Call Inhibit	I S	Switch - CNCE CNCE - CSCS

SUMMARY OF SWITCHING AND TECH CONTROL FUNCTIONS FI PHASE II VS PHASE III (Concl)

Function	FI INT (Phase III)	Interacting Elements (Phase II)
Traffic Control		
Traffic-Load Control		
Call Restriction	I	Switch - CNCE* - CSCE
Trunk Restriction	S	Switch - CNCE - CSCE
Class Mark Table Mod.	I	Switch - CNCE - CSCE
Routing Tables	S	Switch - CNCE - CSCE
Fixed Directory	I	Switch - CNCE - CSCE
Trunk Group Mod	S	Swtich - CNCE - CSCE
Zone Restriction	I	Switch - CNCE - CSCE
Call Inhibit	I	Switch - CNCE - CSCE
Digit Translation	I	Switch - CNCE - CSCE
ALT. Area Routing	S	Switch - CNCE - CSCE
Quality Monitoring, Network Fault Detection & Diagnosis		
Loops	I	Switch - CNCE
Intercenter Trunk Groups	S	Switch - CNCE - RADIO
Intracenter Trunk Groups	I	SW(1) - SW(n) - CNCE
XMSN Groups	S	CNCE - RADIO
Channel Reassignment Function		
Intercenter Circuits		
Dedicated	S	CNCE - RADIO
Switched	S	Switch - CNCE - RADIO
Local Circuits		
Dedicated	I	Device - CNCE
Switched	I	SW(1) - SW(n) - CNCE
Control Communication Supervision		
Orderwires	S	CNCE - XMSN Systems
Telemetry	S	CNCE - RADIO

Legend

FI Integration:

I Intended Integration With FI Functions (Loop-loop functions only)
S Function Remains Separate From FI

SW(1) - SW(n): A switch to switch interaction within one center (Trunk or Trunk Group)

* CNCE - CSCE - Interaction Not Integrated.

CONTENTS

APPENDIX C

LIST OF ILLUSTRATIONS

1.0 APPENDIX C

1.1 Multiribbon cable analysis.

1.1.1 Data bus concept. The concept of using a flat cable configuration as the intrashelter data bus was discussed in the previous study phase. This data bus uses 350 feet of twisted-pair flat cable composed of twenty twisted-pair wires. The data requirement for each twisted pair is 5Mb/s NRZ with a goal of 10 Mb/s NRZ. The bus must be able to interface up to sixty-four peripherals spaced along the 350 feet.

To demonstrate the feasibility of this configuration and to determine system parameters, a partial configuration of this data bus was constructed and tested in the laboratory.

1.1.2 Hardware considerations. The lab bus consists of four 100-foot sections of 20 pair Twist'N'Flat™ planar cable from Spectra-Strip. The Twist'N'Flat™ 20-pair cable consists of stranded 28 AWG round conductors insulated with color-coded PVC, twisted into pairs and laminated between layers of PVC film to form a planar cable. Twisted pair sections 18 inches long alternate with 2-inch flat sections in which the conductors are laminated in parallel on 0.05 inch centers. The flat sections are used as termination points for Insulation Displacement Connectors (IDCs).

Refer to Figure C-1 for the system configuration. Up to 22 driver/receiver pairs can be connected to the main 400-foot cable via six-foot Twist'N'Flat™ cable stubs. The six foot stubs were made by dividing some 20 pair Twist'N'Flat™ cables into two ten-pair cables. Insulation Displacement Connectors are used to connect the 100-foot cable sections together and the stubs to the cables. The 22 driver/receiver pairs are divided up on four wire-wrap boards with six pairs on each of three boards and the other four pairs on the fourth board. This is a compromise between one common power supply with one ground return and 22 power supplies with 22 separate ground returns. Only the main 400-foot cable is terminated at both ends. The stubs are not terminated. The single-point ground concept is used since this is the probable ground configuration in an actual system.

The line drivers are SN75113 dual differential types with 3-state outputs. Dual in-line switches on each wire-wrap board provide for controlling the 3-state mode. The high-impedance state control for each driver output is essential since only one driver can transmit on the data bus at a time. The line receivers are SN75115 dual differential types. Figure C-2 shows one-half of a dual in-line pack each for the driver and the receiver. Low-power Schottky TTL gates are used to buffer the input signal to the drivers from the data generator. When the high-impedance (HiZ) control line is grounded, the driver is placed in the high-impedance output mode.

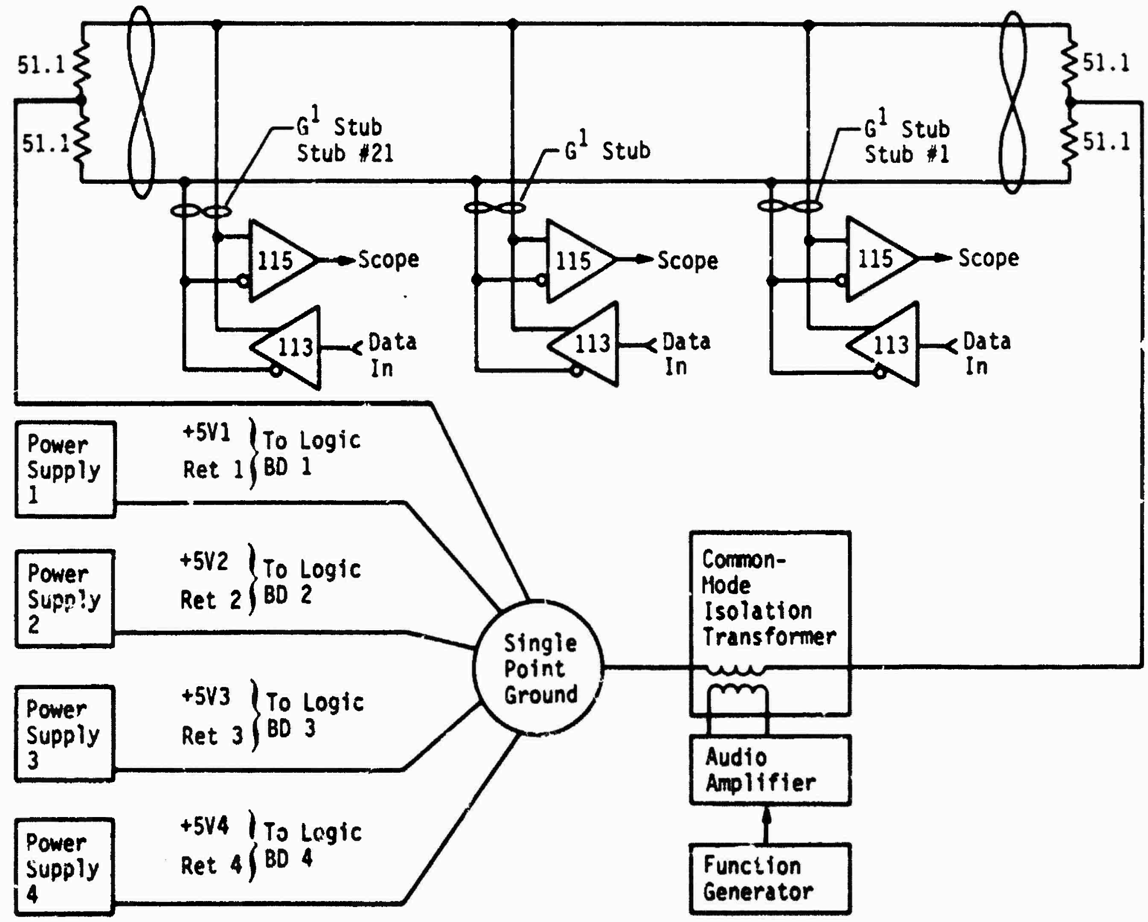


Figure C-1. System configuration.

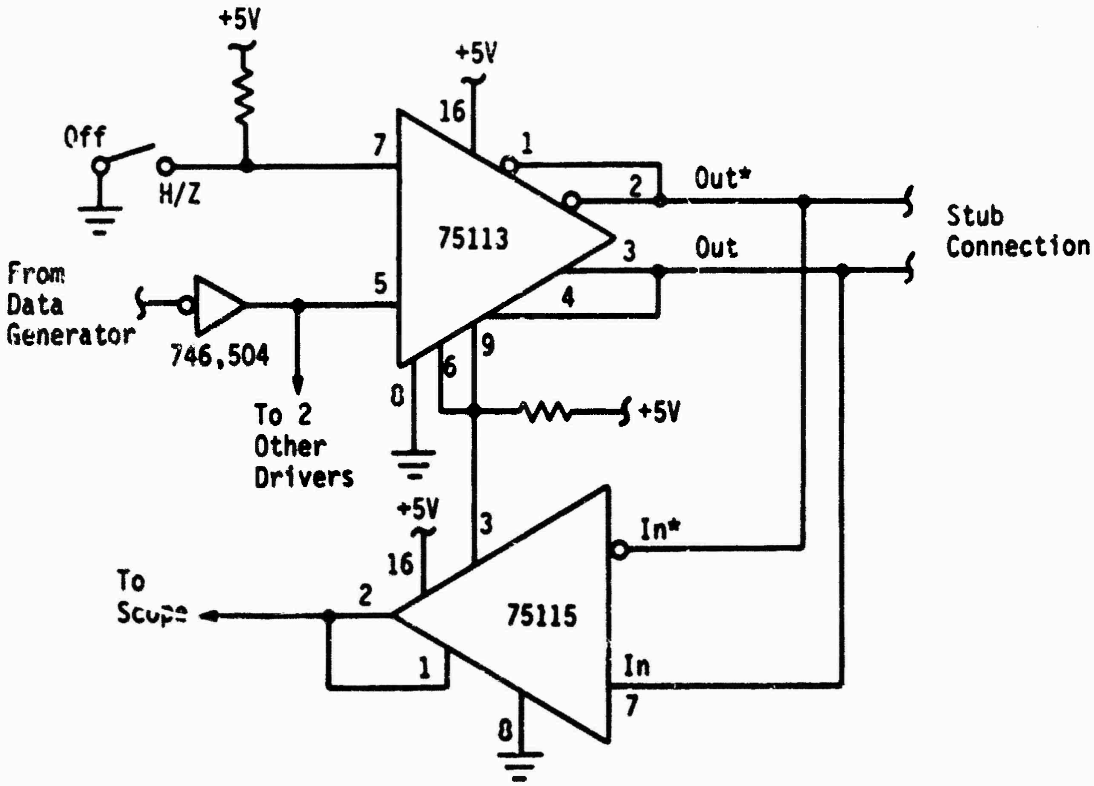


Figure C-2. Typical driver/receiver schematic.

Figure C-3 shows the hardware setup. The complete setup in Picture A shows the electronics, test equipment, and the 400-foot main cable with all 21 stubs connected to it at approximately 20-foot intervals. Both ends of the main cable are terminated at the box shown in Picture B. Even though only one twisted pair is used in the stubs and main cable for most tests, several other pairs of the main cable are terminated. These pairs are used in the crosstalk tests described later. The single-point ground is the bus bar on the box in Picture B. The terminating resistors and the wires from each power supply are connected at this bus bar. This single-point ground configuration was shown in Figure C-1. The four wirewrap boards are mounted in the electronics chassis shown in Picture C. The two connectors at the top of the chassis are used as test points for monitoring. The data generator input for each of the four boards is provided by the BNC connectors on the lower front of the chassis.

The test equipment used in obtaining the data is as follows:

a. HP 182A Oscilloscope
b. HP 197A Oscilloscope Camera
c. HP 5246L Electronic Counter
d. HP 3760A Data Generator
e. HP 3300A Function Generator
f. McIntosh 60 Audio Amplifier
g. Solar Electronics Type 6220-1A Audio Isolation Transformer
h. Laboratory Power Supplies

The HP Data Generator provided both the square wave (1010) waveforms and the pseudo-random data sequence.

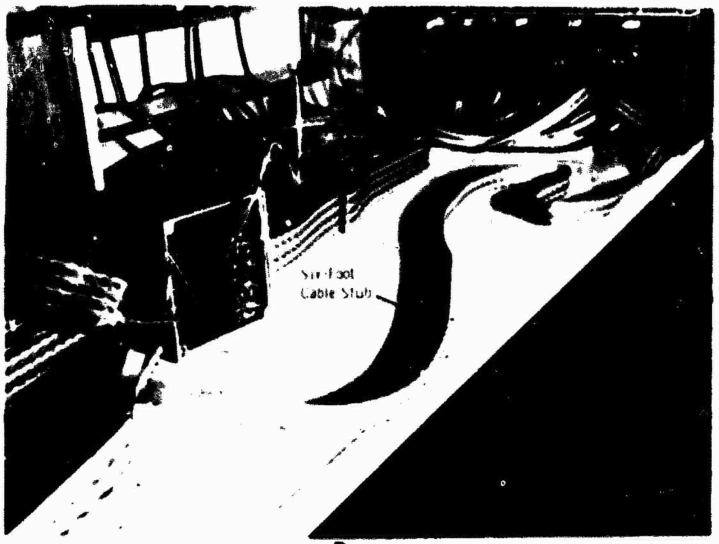
1.1.3 Theoretical considerations. The test configuration shown in Figure C-1 incorporates several important results and conclusions from transmission line theory. A balanced, twisted-pair transmission line is used. External transverse magnetic field noise induces equal and opposite currents on the line because of the adjacent twists on the wires. Thus, this noise is cancelled out. Also, both wires are almost equally affected by electrostatically coupled noise, assuming perfectly balanced lines. This, along with any system ground potential differences, results in a net common-mode signal with respect to the system ground return. Thus the noise appears at the receiver input terminals as a common-mode signal, while the driver output appears as a differential signal.

If the differential receiver has a sufficiently high common-mode operating range, it can discriminate between the noise and driver signals. The ground return connection between the differential line driver and receiver is not part of the signal circuit. Thus, system performance is not affected by circulating ground currents. In a high EMI environment, differential operation should provide the noise immunity necessary for feasible system operation. The line receivers chosen for this test have a $\pm$ 15v common-mode input voltage range.

Complete Setup
Cable Electronics
Test Equipment

A

Line Termination
and Single-Point
Ground Box



B

Electronics Chassis

C

Figure C-3. Hardware setup.

Every transmission line exhibits a characteristic input inpedance designated Z_0. If the operating frequency is above approximately 100 kHz, this characteristic impedance is best approximated by the lossless line equation:

$$Zo \approx \sqrt{\frac{L}{C}}$$

where: C = line capacitance per unit length.
L = line inductance per unit length.

When the transmission line is terminated by a resistance equal to the line's characteristic impedance, line reflections at the termination are virtually eliminated. This allows the system to operate at high data rates since there are no reflections from one transmitted pulse to interfere with the next pulse. The Twist'N'Flat™ cable has a characteristic impedance of approximately 105 ohms. So the line in the lab is terminated with two 51.1 ohm resistors in series.

Figure C-4B shows the two tests for termination with one side of each connected to the ground. Since R_1 or $R_z \ll R_{in}$, most of the noise current will flow through R_1 or R_2 to the ground. Using this termination technique, the common-mode noise at the receiver will be significantly reduced.

After the lab system was built and many oscilloscope pictures had been taken, it was discovered (Appendix A) that this configuration was not optimum. However, it remains so all results obtained from the tests could be correlated. In an actual configuration, the line termination resistors should be ac coupled to ground using large-value capacitors.

Stub length is another important consideration. Since the stub is unterminated at either end, it will produce reflections on the data bus. The permissible stub length is directly dependent upon the risetime of the signal at the stub-line location. A detailed discussion of this dependence is found in Reference 1. The total propagation delay, T, of a line of length l is:

$$T = l\sqrt{LC}$$

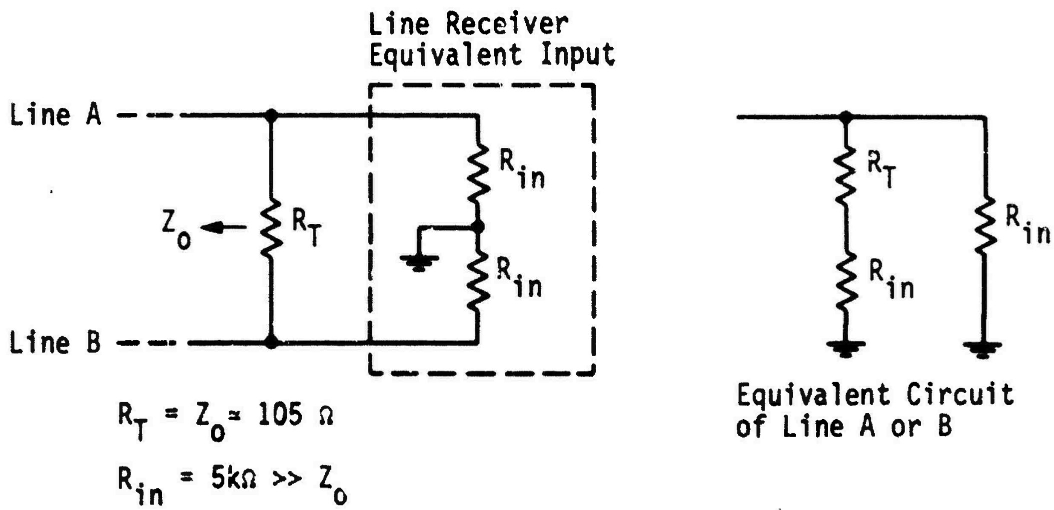


Figure C-4A. Single resistor termination.

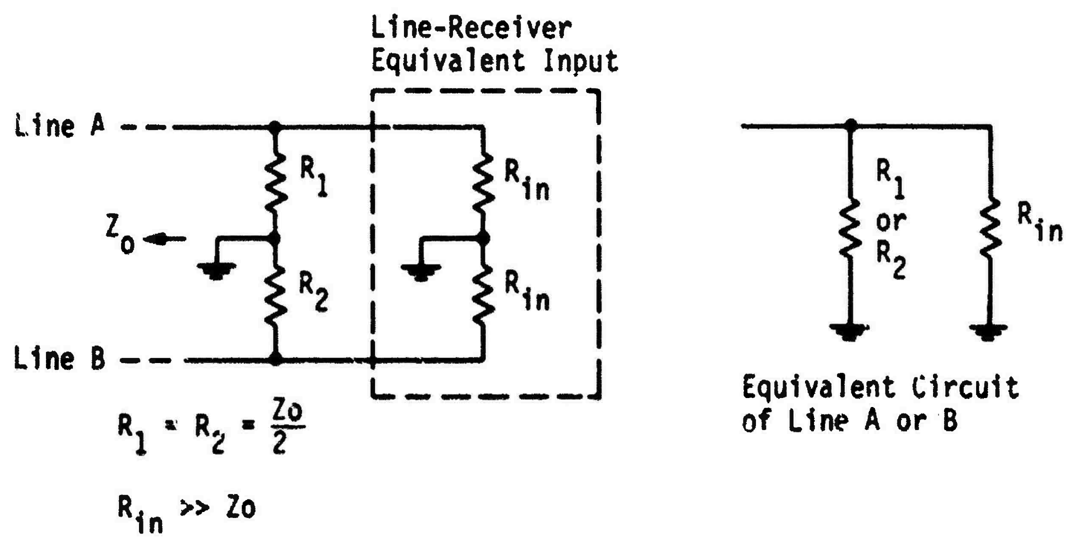


Figure C-4B. Two resistor termination.

where L and C were defined earlier. This time delay should be made very short in comparison to the risetime, t_r, of the signal at the stub location in order to have minimal reflections. A risetime to propagation delay ratio greater than 8 to 1 is considered adequate to prevent the stub from affecting the signal quality. The Twist'N'Flat™ cable has a propagation delay of 1.7 nanseconds per foot. For a 10Mb/s NRZ signal, the fundamental frequency is 5 MHz. The minimum risetime of this frequency, f, is:

$$t_r = \frac{0.35}{f} = \frac{0.35}{5\ \text{MHz}} = 70 \text{ nanoseconds}$$

This allows the stub propagation delay, T , to be:

$$T = \frac{tr}{8} = \frac{70}{8} \approx 8.75 \text{ nanoseconds}$$

and the corresponding stub length, l, is:

$$l = \frac{T}{1.7 \text{ nanoseconds}} = \frac{8.75}{1.7} \text{ ft} \approx 5.15 \text{ ft.}$$

The stubs for the lab test are six feet long. This allows a realistic test of the stub's affect upon the signal.

1.1.4 Data patterns. Two types of data patterns are used in testing. The first type is alternate ones and zeros. This pattern allows the signal delay, risetime, ringing and other characteristics to be determined. The other type is a pseudo-random data pattern. Each pseudo-random sequence (PRS) used in the lab system contains 2^{15} -1 bits. This PRS allows the generation of an oscilloscope eye pattern for measuring data signal quality. The PRS is generated by an HP 3760A Data Generator. Several data parameters can be obtained from the eye pattern. Signal rise and fall times can be measured and peak-to-peak signal transition jitter can be determined. Signal undershoot or overshoot can be seen and be used to determine whether the transmission line is properly terminated. The eye "openness" is a measurement of the system frequency response margin. The eye pattern is detailed in Reference 1.

1.1.5 Line driver common-mode problem. A problem exists with line drivers in the 3-state mode when negative common-mode signals more negative than aproximately -1 volt are present. This is detailed in Appendix C-1. The *substrate diode* between the driver's output pin and the substrate starts conducting when the output is more negative than the substrate by approximately 1 volt. This can degrade or burn out the integrated circuit or the bond wires. This is not dependent on the positive supply voltage to the driver. A new type of party-line driver eliminating this problem is expected to be available next year. This phenomona is shown in the Figure C-20C scope picture and is discussed in the common-mode voltage section.

1.1.6 Initial test. After one wirewrap board was completed, a test was conducted using just the main transmission line without the stubs. One driver and one receiver were connected to the line. The receiver end of the line was terminated using two 51.1 ohm resistors to ground return. The 100-foot cable sections were left in rolls. All data were taken with respect to ground; no differential measurements were taken. The schematic in Figure C-5 show the points at which the data were taken.

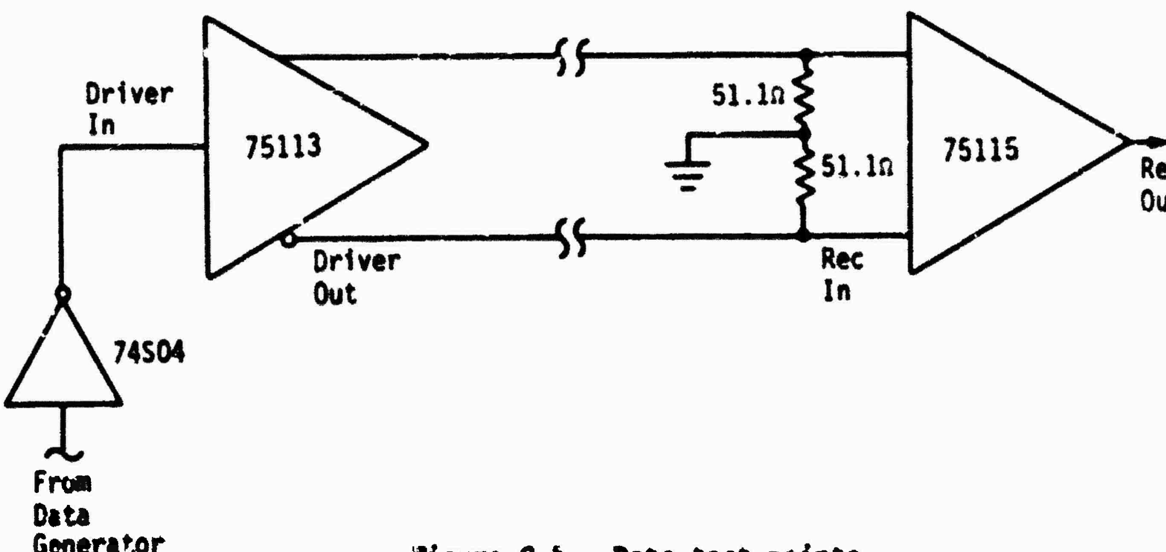


Figure C-5. Data test points.

Figures C-6 and C-7 show the results. The data was simulated 10Mb/s NRZ except for the last two pictures of Figure C-7, which were 5Mb/s NRZ. The arrows pointing to specific spots on each waveform show the propagation time delay due to the driver/receiver logic and/or the cable delay.

The following observations can be made concerning the pictures in Figures C-6 and C-7.

Note the *rounding* of the REC IN waveform as the line length increases. This is due to the difference in attentuation and propagation velocity of the signal frequency components. This is discussed in Reference 1. In essence, the higher frequency components propagate down the line faster, but are attenuated more, than the low frequency components. This phenomona manifests itself by a relatively fast initial rise of the line output signal as the high-frequency components arrive first. The later arrival of the low-frequency components cause the signal to rise to the final value more slowly. Also the additional capacitance of the longer cable limits the cable's frequency response.

The propagation delays of both the driver and receiver is approximately 35 nanoseconds (ns). The propagation delay of 400 feet of cable is approximately 750 nanoseconds. So the propagation delay of the cable per foot, δ, is

$$\delta = \frac{750 \text{ ns} - 35 \text{ ns}}{400 \text{ ft}} = 1.79 \text{ ns/ft}$$

Even though the cable lengths and the scope picture measurements are not exact, this agrees quite closely with the published $\delta = 1.7$ ns/ft.

At 400 feet, the receiver waveforms at 10Mb/s NRZ look good. These results allowed continuation with the more realistic test configuration shown in Figure C-3.

1.1.7 Test configuration. All the following tests were run using the hardware shown in Figure C-3. The text configuration followed Figure C-1 with the function generator, audio amplifier, and isolation transformer connected only during the common-mode signal tests.

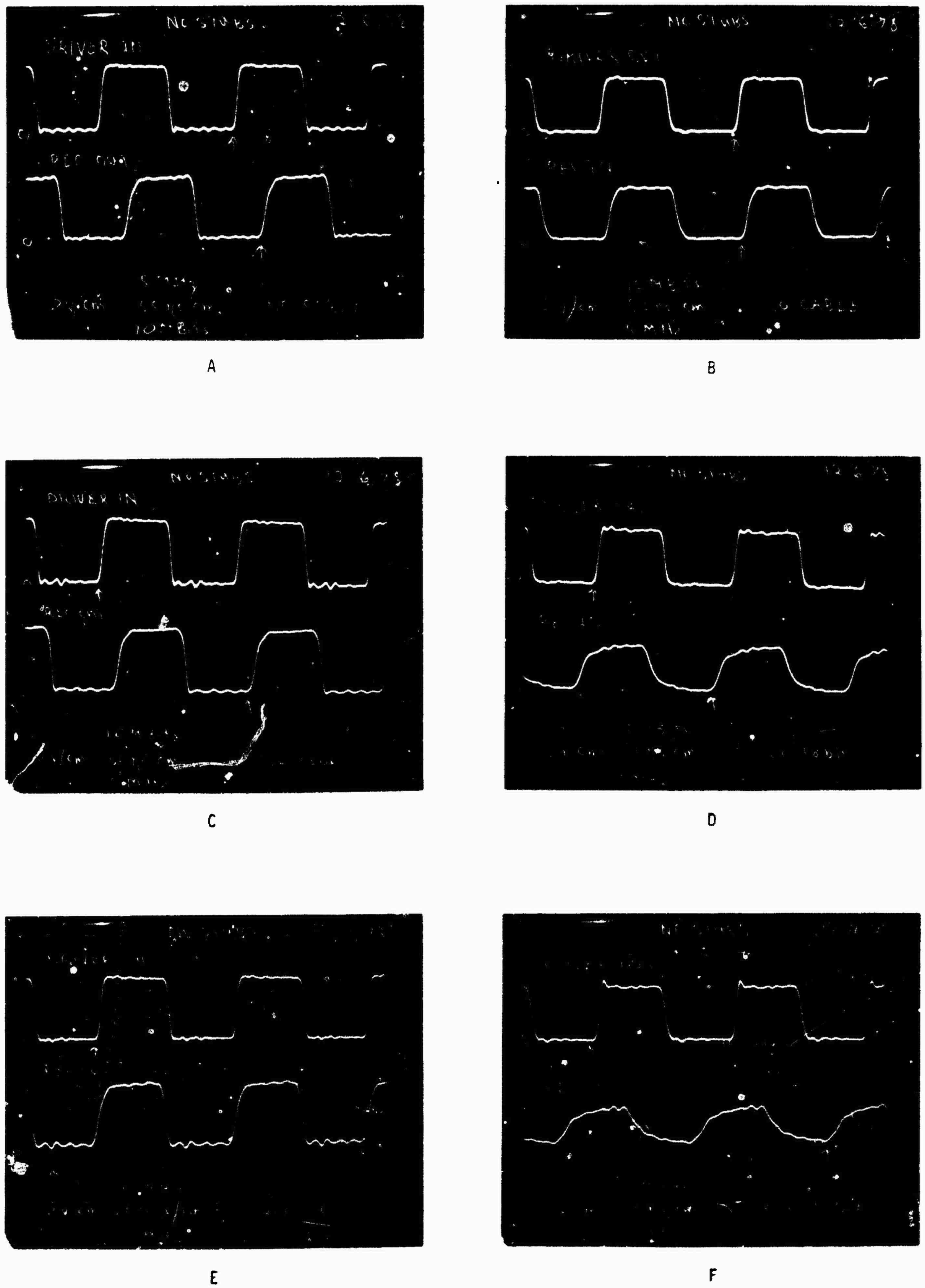
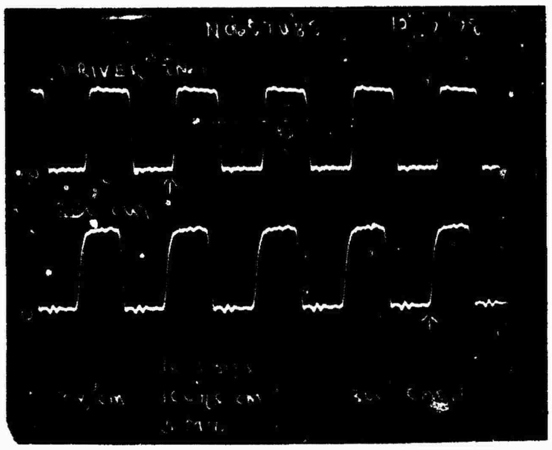
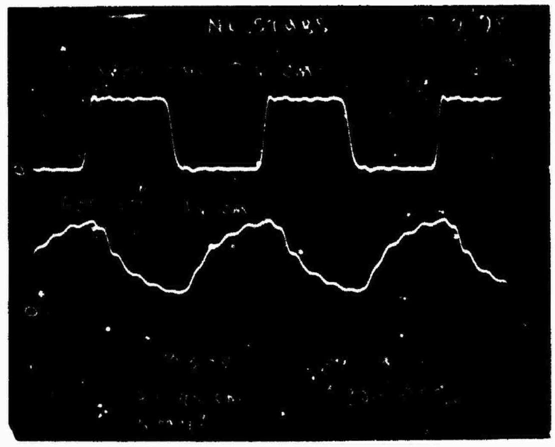


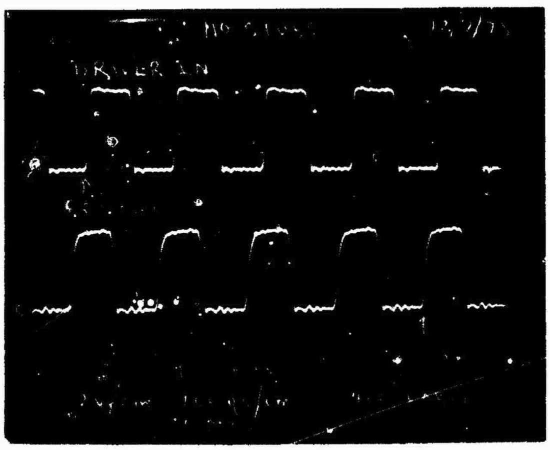
Figure C-6. Initial test results.



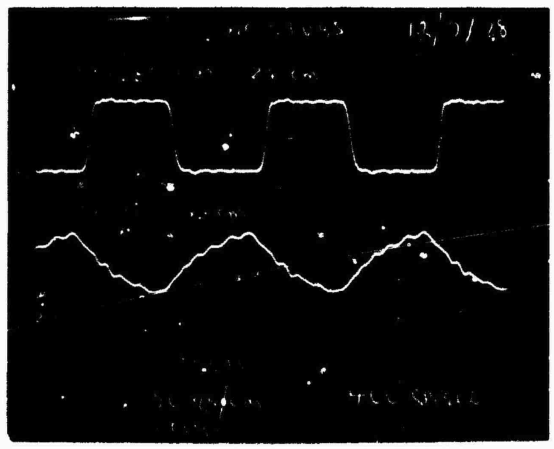
A



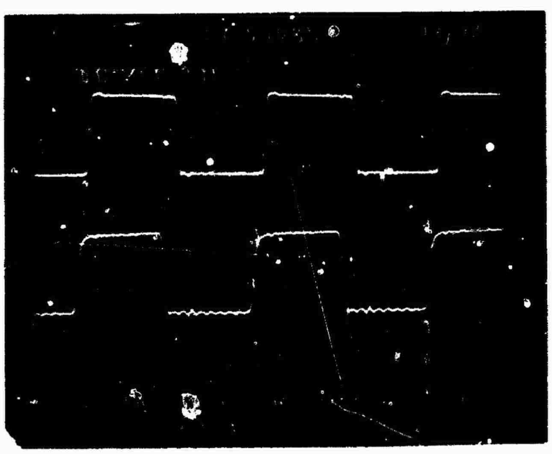
B



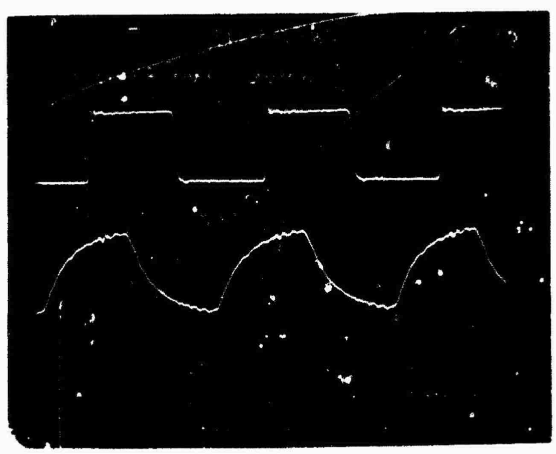
C



D



E



F

Figure C-7. Initial test results.

All data were taken single-ended with respect to the ground for that particular wire-wrap board. The Driver Out and Receiver In data were taken on the inverting (NAND) terminals. The Driver In data were taken right at the input to the drivers.

The propagation delay in a driver/receiver pair was measured at approximately 34 nanoseconds. This was measured on the scope using a driver/receiver pair wired together on one of the wirewrap boards. The same driver/receiver-pair frequency response was checked up to 25Mb/s NRZ using the pseudo-random sequence data and observing the eye pattern on the scope. The eye pattern was excellent up to 25Mb/s. This verified that the driver/receiver was not the limiting factor in the system frequency response.

1.1.8 Test using 100-foot cable with stubs. The first test performed with the full test setup used 100 feet of cable with up to 21 stubs connected. The stubs were equally spaced approximately every 5 feet along the cable. Stub number 1 was at one end of the cable and stub number 21 at the other end. Figures C-8, 9, and 10 show the results of this test.

Comparing Picture 8A with 8B, one can note the amplitude decrease of both the Driver Out and Receiver In when the line is driven. As stubs are added, the Driver-Out waveshape does not change as drastically as the Receiver In, which becomes more sinewave in shape. This is due to the added cable capacitance limiting the frequency response.

The propagation delay between Driver Out and Receiver In in Picture 8B is approximately 220 nanoseconds. This same delay in Picture 8F is approximately 240 nanoseconds. Apparently the 15 stubs with their impedance load on the line make the line length electrically longer than the 100-feet of main line plus two stubs.

The waveforms for Pictures 8F and 9D are similar.

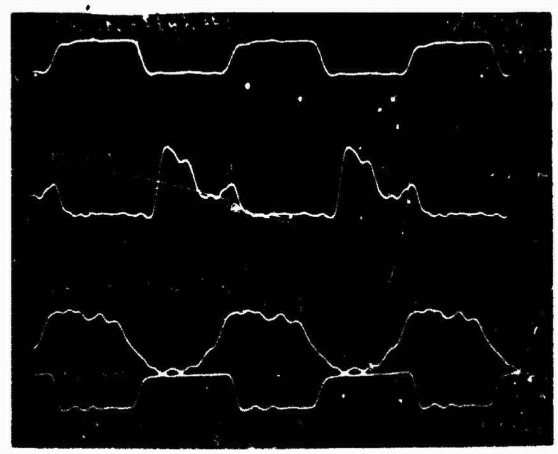
The eye patterns show the frequency response of the system. The response is excellent at 10Mb/s NRZ as shown in Pictures 9E, 9F, and 10A. The eye is closing in Picture 10D, at 15.6Mb/s NRZ and is closed at 17.4M Bits NRZ.

Cable length of 100 feet should support 10M Bits NRZ easily.

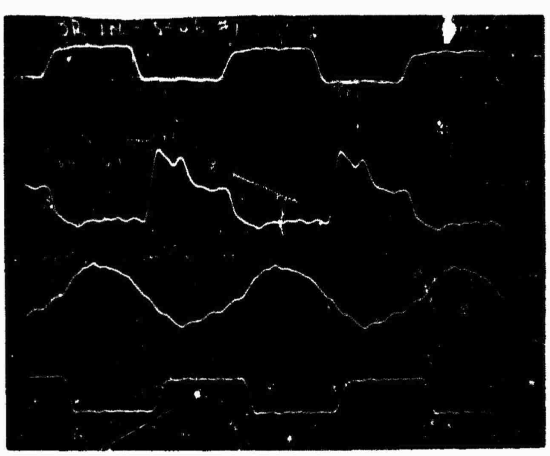
A

B

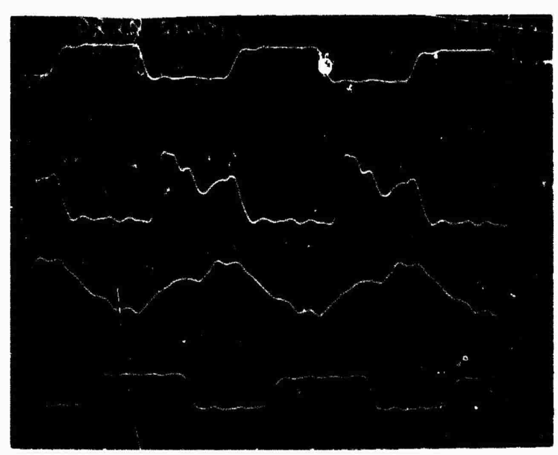
C



D

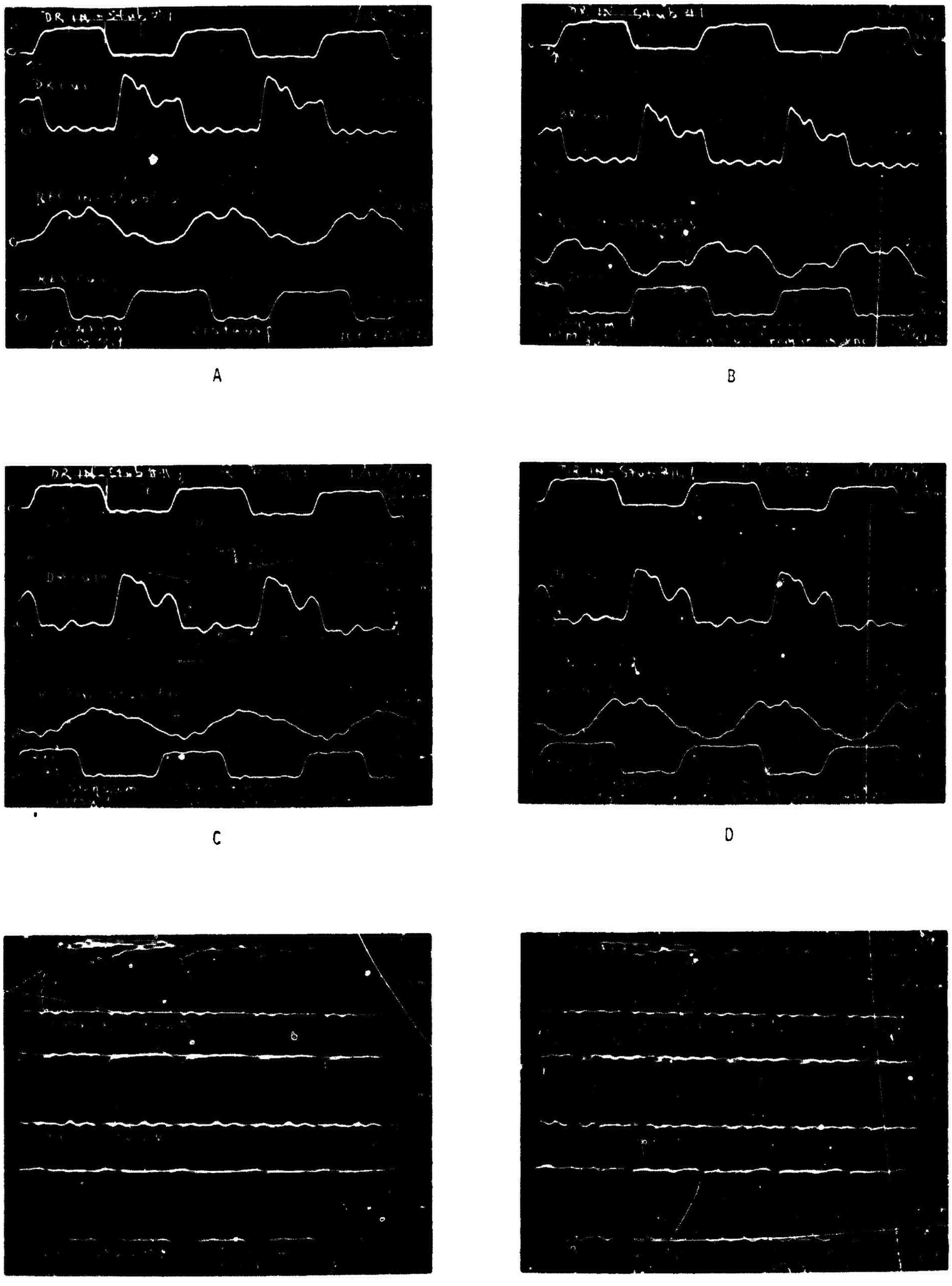


E



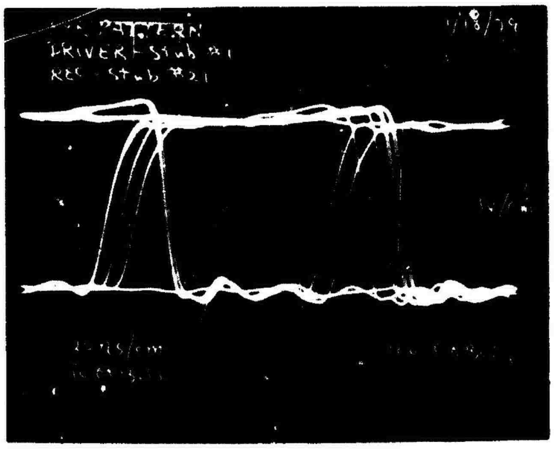
F

Figure C-8. 100-foot cable with stubs.

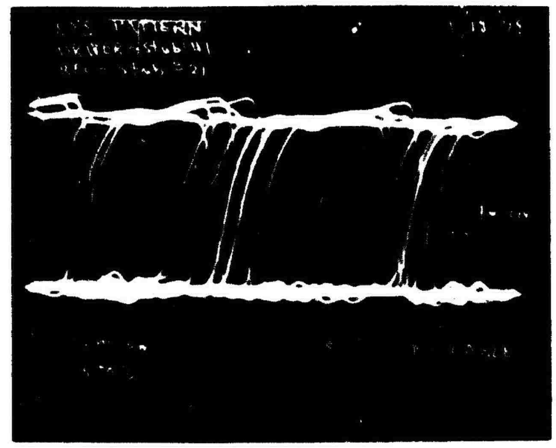


A B C D E F

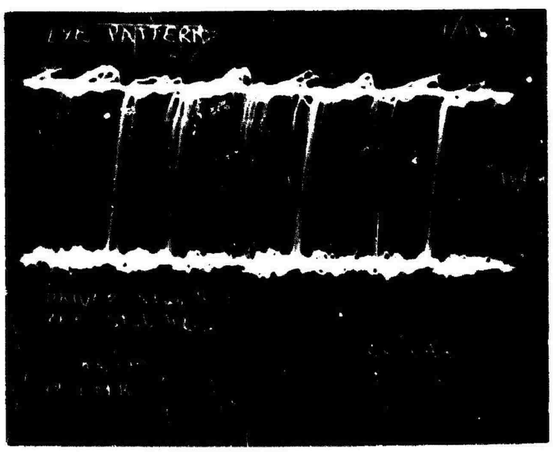
Figure C-9. 100-foot cable with stubs.



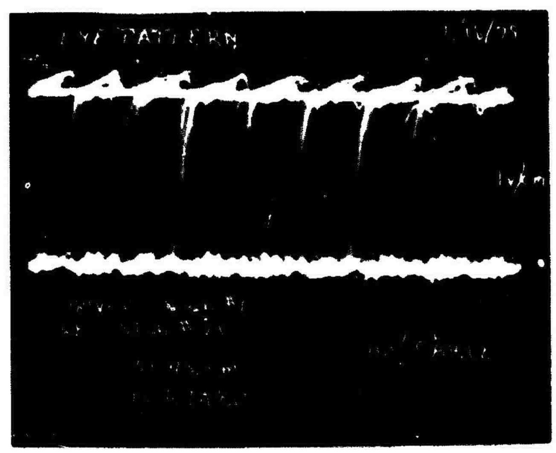
A



B

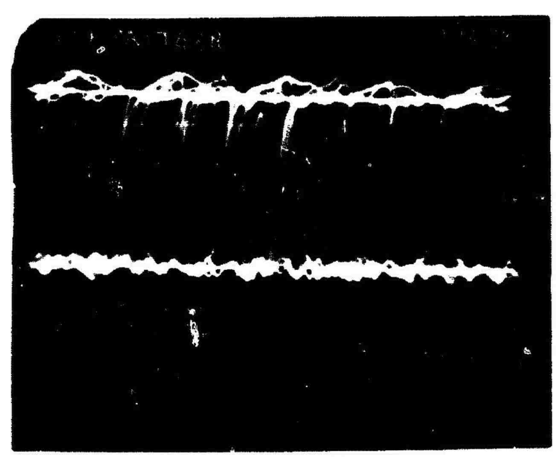


C



D

E



F

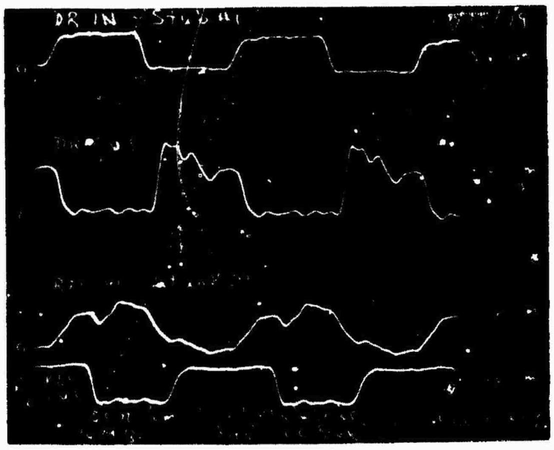
Figure C-10. 100-foot cable with stubs.

1.1.9 Test using 400-foot cable with up to 21 receivers. In this test, all 400 feet of cable were used with up to 21 stubs, each connected to one receiver. The stubs were equally spaced approximately every 20 feet along the cable. Stub number 1 was at one end of the cable and stub number 21 at the other end. Figures C-11 through 14 show the results of this test.

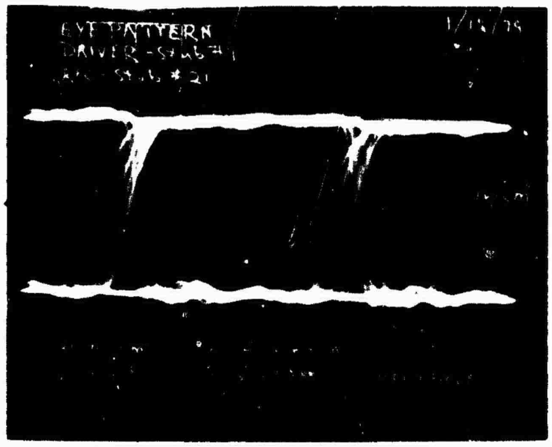
The waveforms and eye pattern of all 21 stubs on the first 100 feet of cable, Pictures C-11A and -11B, are very similar to the corresponding Pictures 9A and 10A of the 100 foot cable in Figures C-9 and C3-10. This is a good indication that the lines are properly terminated and thus the extra 300 feet of line presents just an equivalent dc load to the driver.

Picture C-13 shows approximately 890 nanoseconds delay from one end of the cable to the other with all stubs on the line and 21 receivers connected to the stubs. With just one driver and receiver at opposite ends of the 400 foot line using no stubs, the approximate delay is 750 nanoseconds as shown in Figure C-7, Pictures C and E. So the 21 stubs and 20 extra receivers effectively increase the electrical line length. Most of the increase is probably due to the capacitance of the unterminated stubs.

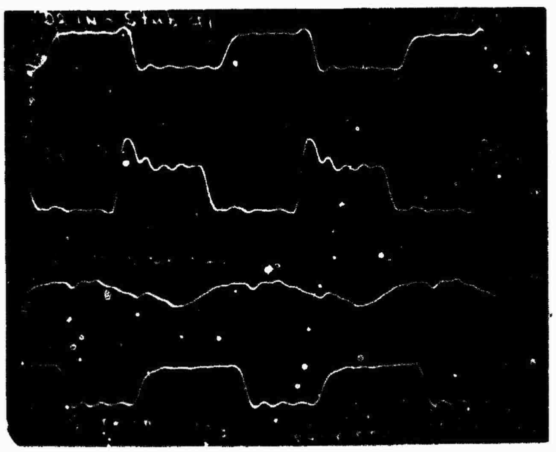
The time delays at various points on the cable were measured with the driver on Stub 1. The results are tabulated in Table C-1. These values include the 34 nanoseconds propagation delay in a driver/receiver pair.



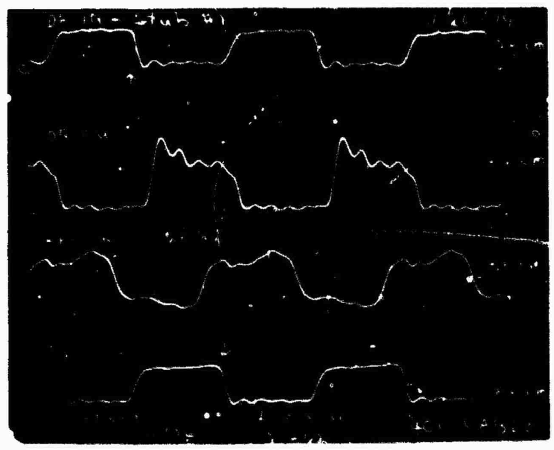
A



B

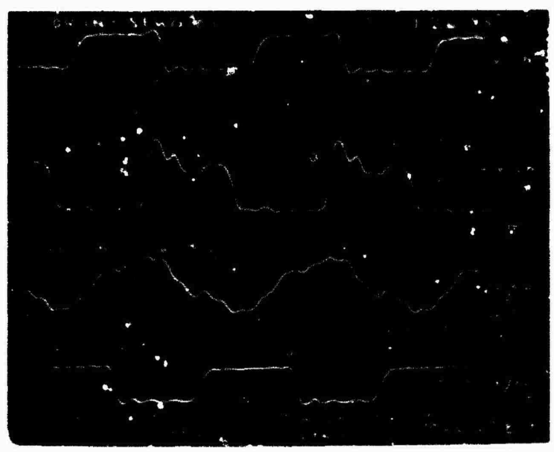


C



D

E



F

Figure C-11. 400-foot cable with up to 21 receivers.

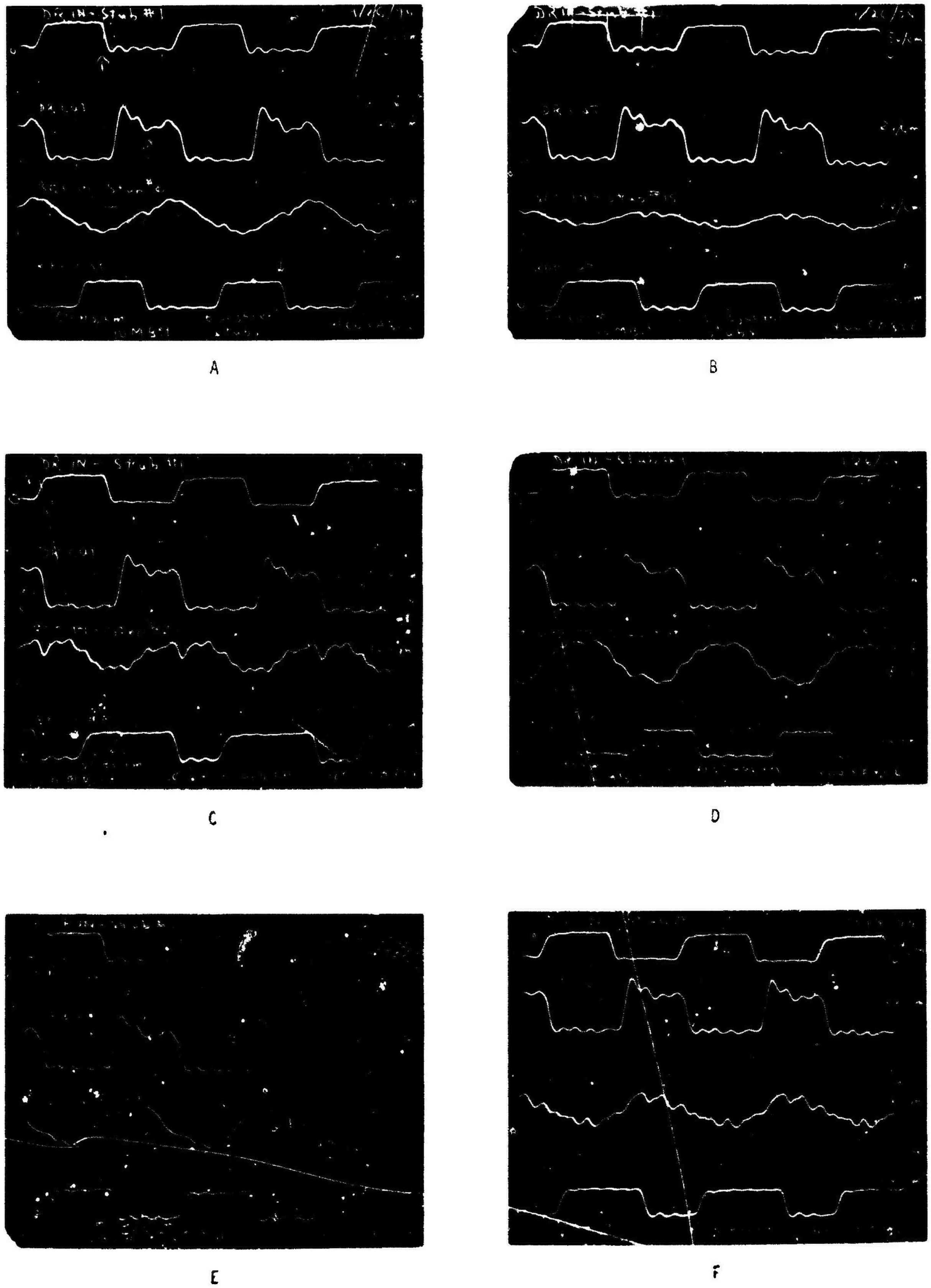
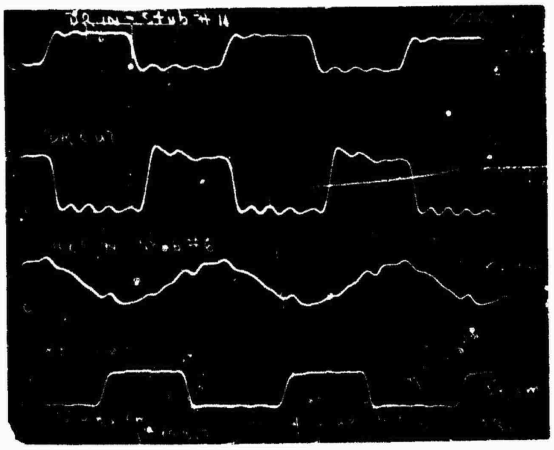
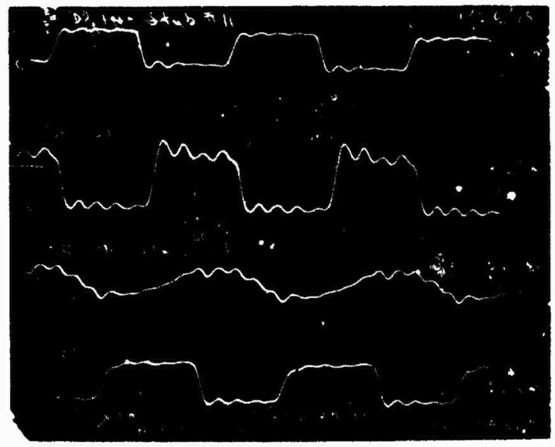


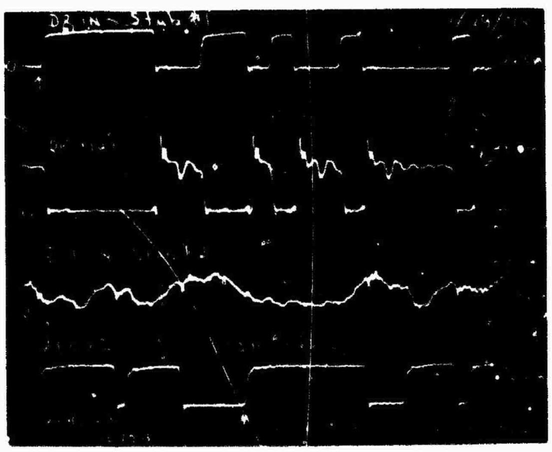
Figure C-12. 400-foot cable with up to 21 receivers.



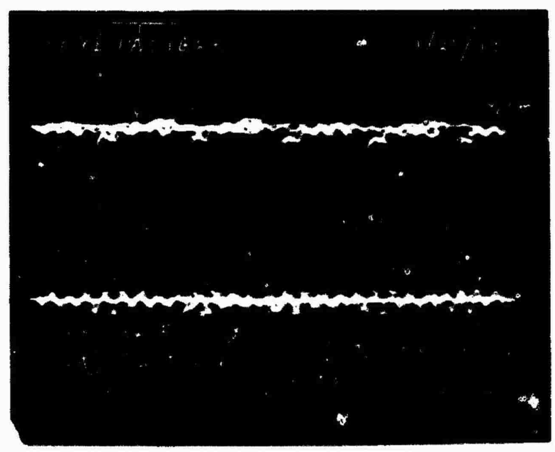
A



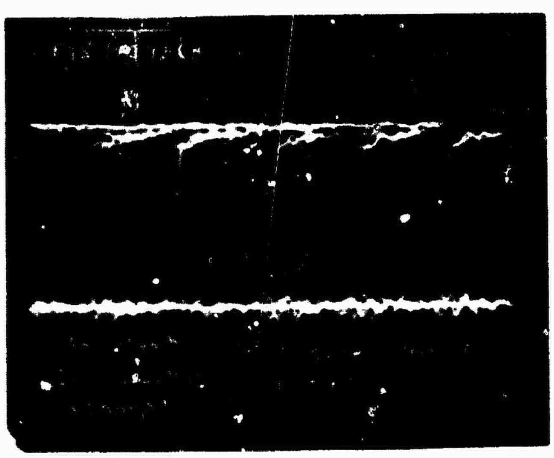
B



C

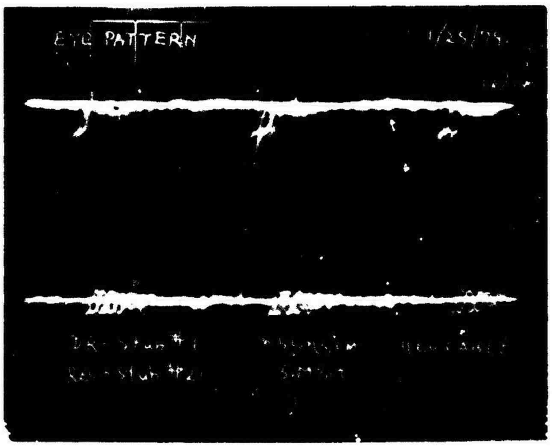


D

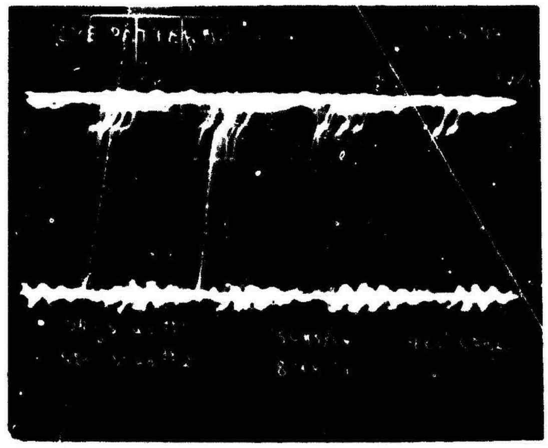


E

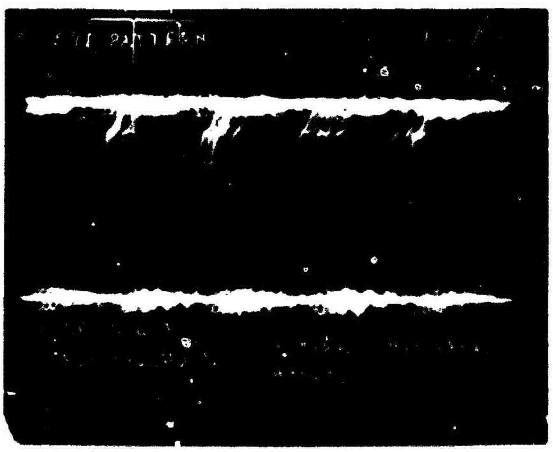
Figure C-13. 400-foot cable with up to 21 receivers.



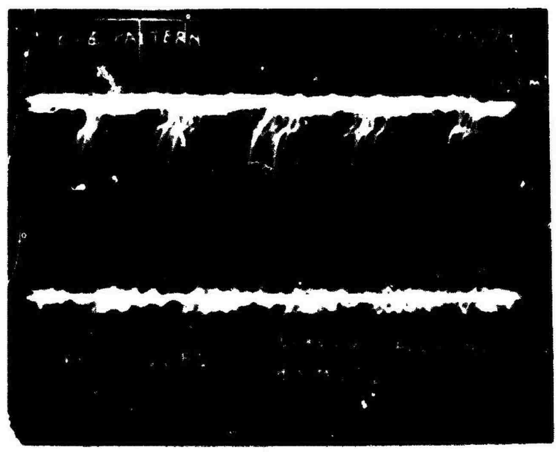
A



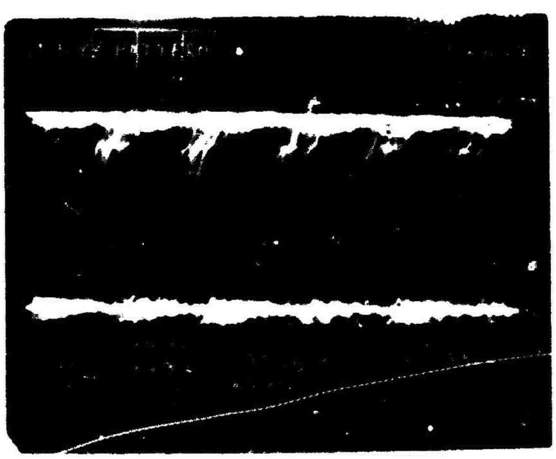
B



C



D



E

Figure C-14. 400-foot cable with up to 21 receivers.

TABLE C-1. SYSTEM DELAYS.

Stub Number	Delay (Nanoseconds)	Stub Number	Delay (Nanoseconds)
2	90	9	410
3	135	17	740
4	170	18	800
5	215	19	830
6	265	20	880
7	310	21	890
8	360		

In Pictures C-11C, -12B, and -12C the REC OUT waveform is asymmetrical. This is a good indication that these configurations are reaching their upper frequency response, especially 12C. The REC IN amplitude is low and has a sinewave appearance. Note that when the line is driven from the center, as in Picture C-13B where the driver is at the 200 foot point, the REC OUT looks very symmetrical.

The eye patterns show that even at 340 feet, stub 18, the 10M Bits NRZ is still good. At 400 feet on stub 21, the eye is starting to close at 9.5Mb/s NRZ and is completely closed at 10Mb/s NRZ.

Notice that in the eye patterns where the rise and fall times are not overlapping, as in Pictures C-13D and -E, the driver/receiver system favors the logic-zero state. That is, the eye opening at the bottom (logic zero) is wider than the top (logic one). This is probably due to an unbalance between the driver output and the receiver threshold. As shown in Reference 1, the crossing point of the rise and fall times is the optimum receiver threshold level for minimum jitter. Obviously this should occur as close to the center of the logic zero and one voltage levels as possible for optimum noise immunity. The rise/fall time crossing is near the bottom in the lab system. Centering this crossing should be a consideration in the data bus design.

1.1.10 Receiver simulation. The actual data bus system requirement is for up to 64 stations along the cable. In order to more closely duplicate this situation without adding more driver/recever pairs, a resistive/capacative load simulating two additional receivers was added to each of the 21 receivers. Thus the load at each stub is now one driver in the high-impedance mode (negligible effect on the system), one actual receiver, and two simulated receivers. From the SN75115 receiver specifications, the resistive load at each receiver is typically 5k ohms to ground at 25°C. For worst case, this resistance was assumed to be 2.5k ohms. From Appendix C-1, the worst-case capacitance to ground for each receiver is approximately 5 pf. Figure C-15A shows the resistive/capacitive (RC) load for one receiver. Two of these loads were paralleled to simulate two receivers. Figure C-15B shows the actual values used in the simulation and how they were connected to each actual receiver on the wirewrap boards.

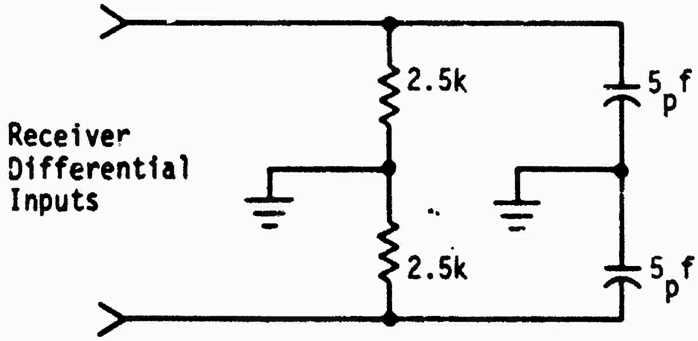


Figure. C-15A. Simulated receiver input.

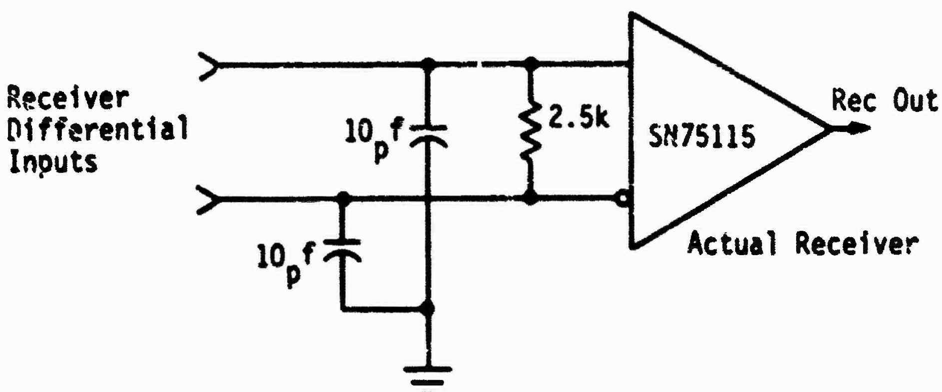


Figure C-15B. Actual receiver and two simulated receiver inputs.

This configuration was used for the remainder of the tests. The pictures for these tests are labeled "RC Simulation - 42 Rec" or "RC Sim -42 REC" to designate 42 resistive/capacitive (RC) simulated receiver inputs and 21 actual receivers. Keep in mind that each time one stub is added to the main cable, the equivalent of one driver in the high-impedance state and three receivers are added into the system. The driver that is driving the system is, of course, not in the high-impedance state.

The stubs were equally spaced approximately every 20 feet along the cable. Stub number 1 was at one end of the cable and stub number 21 at the other end.

1.1.11 Cable types. The remainder of the tests use two different types of cables. The Spectra-Strip Twist'N'Flat™ cable is the one used for all previously described tests and those following so designated. The pictures that do not specify a cable type were taken with the Twist'N'Flat™ cable described earlier. The second type of cable tested was the Spectra-Strip Spectra-Zip™ cable. This 20-pair cable consists of uninsulated, stranded 28 AWG round conductors laminated between layers of gray PVC film to form a planar cable with 0.05 inch centers. The same insulation displacement connectors (IDCs) were used with this cable. The six-foot stubs used with this main cable were the original Twist'N'Flat™. The system configuration and the stub spacing were kept the same for both cable types.

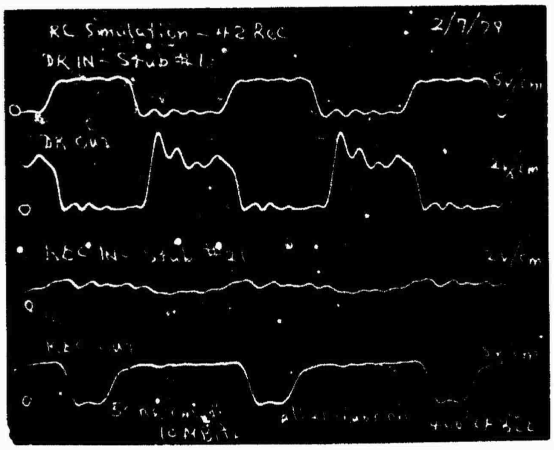
1.1.12 Test using 400-feet Twist 'N'FlatTM cable. This test used the receiver simulation described above. The picture results are shown in Figures C-16 and C-17.

The REC OUT asymmetry is even more pronounced in Picture C-16A then it is in Figure C-12, Picture C with only 21 receivers on the line. This suggests, and is confirmed by the eye patterns, that the frequency response is even less than before. The DR OUT signal looks very similar in the two pictures.

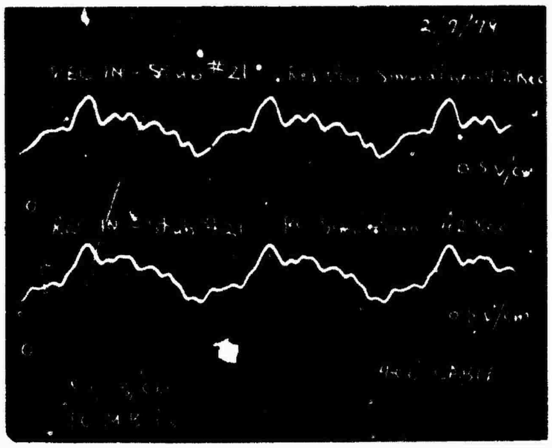
Picture C-16B shows the REC IN at stub 21 with the driver on stub 1 under two conditions. The top waveform has taken after just the resistive load for each of the 42 simulated receivers was wired onto the wire-wrap boards. The bottom waveform shows the RC network wired as in Figure C-15B. Note the "smoothing" of the signal with the capacitors in the circuit as compared to the top waveform.

At 300 feet, stub 16, the eye pattern looks good at 10Mb/s NRZ. However, at 340 feet, stub 18, the eye is starting to close at 9Mb/s NRZ and is closed at 9.5Mb/s. This is a frequency response decrease of approximately 1 MHz from the previous test of 21 receivers.

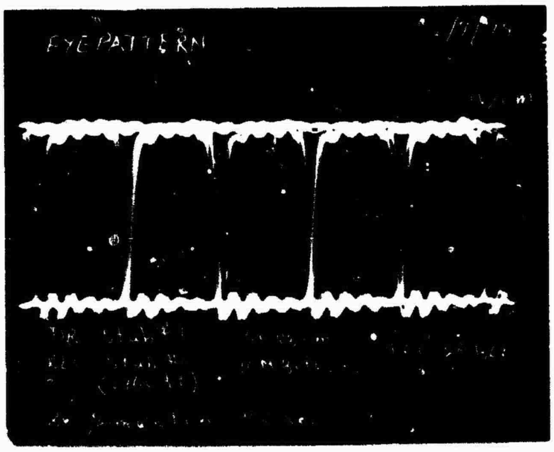
At 400 feet, stub 21, the 5Mb/s NRZ eye pattern is very good. The eye is closing at 7.5Mb/s NRZ and is completely closed at 8Mb/s NRZ. The system frequency response at this length has decreased approximately 2 MHz from the previous 21 receiver test.



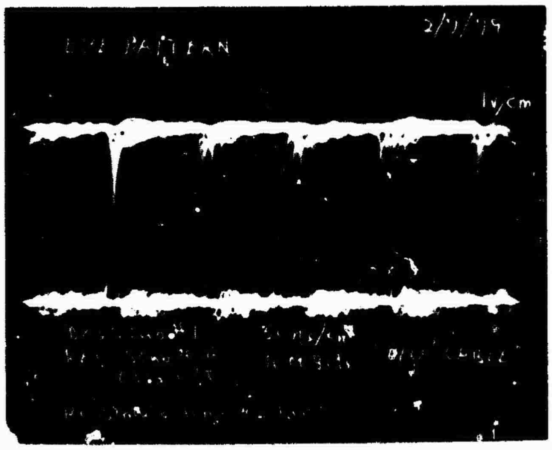
A



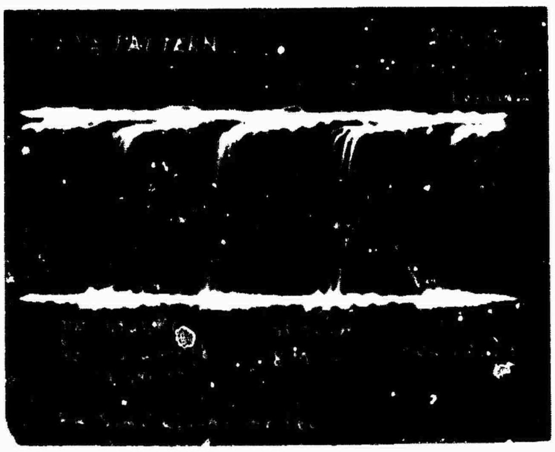
B



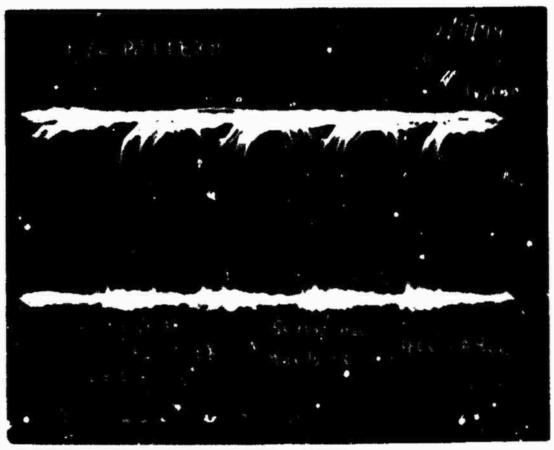
C



D

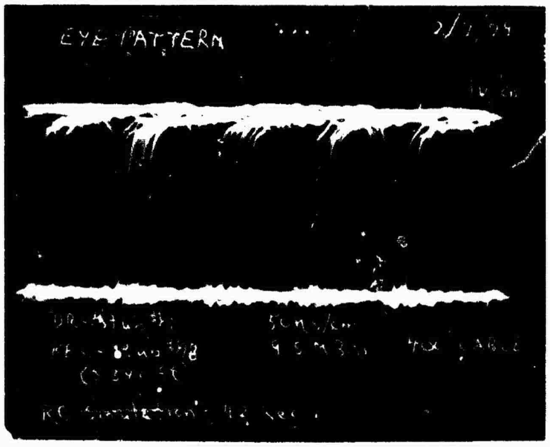


E

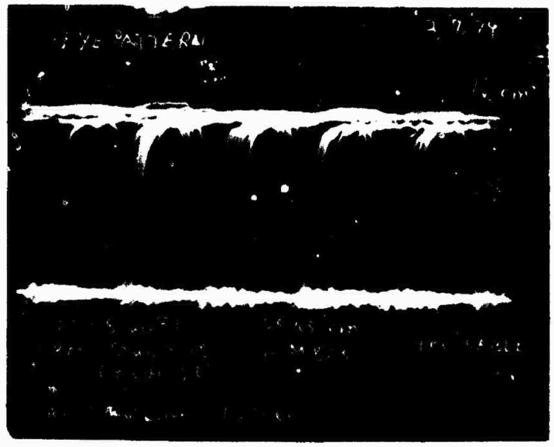


F

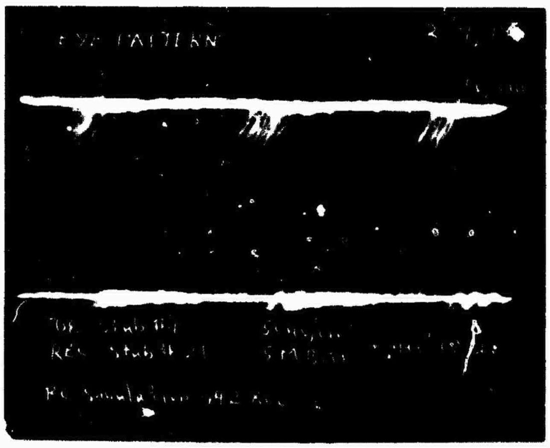
Figure C-16. 400-foot Twist'N'Flat™ with simulated receivers.



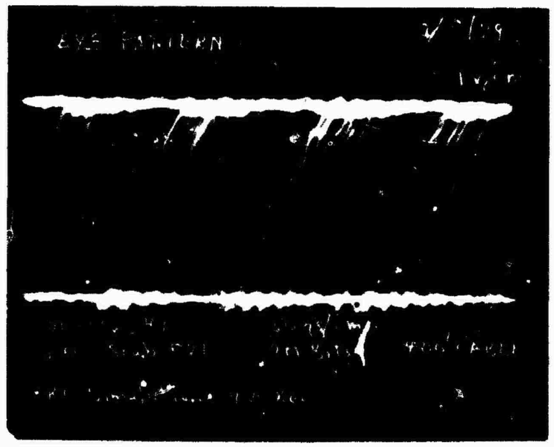
A



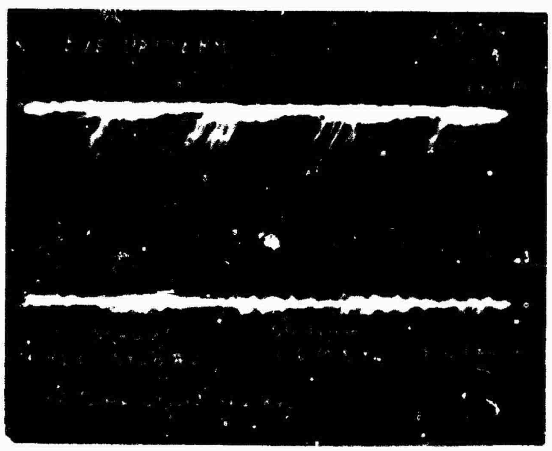
B



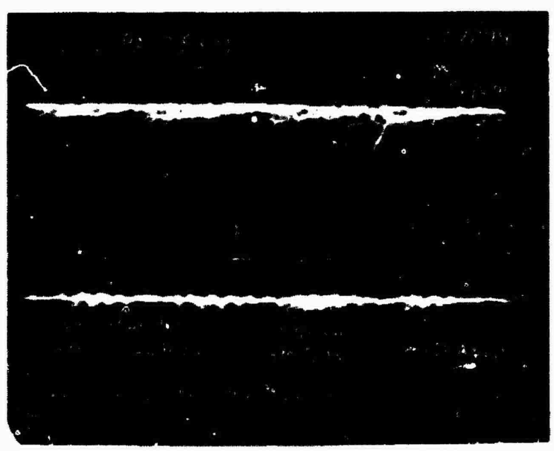
C



D



E



F

Figure C-17. 400-foot Twist'N'Flat™ with simulated receivers.

1.1.13 Test using 400-feet Spectra-Zip™ cable. This test also used the receiver simulation and, as in all of the above tests, was used to determine the frequency response of this particular cable. Figures C-18 and C-19 show the results.

For Picture C-18A, the signal frequency was decreased so that the REC OUT waveform had approximately the same asymmetry as in Figure C-16, Picture A. To accomplish this, the frequency had to be decreased to 9Mb/s NRZ. This suggested that the freqeuncy response of this cable was about 1 MHz below the Twist'N'Flat™ cable. The eye patterns confirm this.

At 100 feet, stub 6, the eye pattern locks very similar to the Twist'N'Flat™ Figure C-16, Picture C.

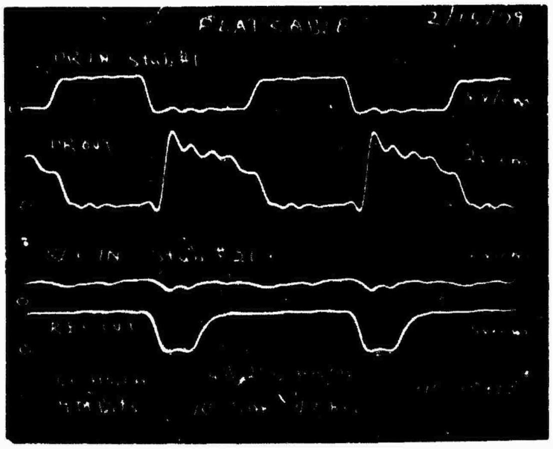
At 300 feet, stub 16, the eye is closing at 9.5Mb/s NRZ and is closed at 10Mb/s NRZ. The eye of Picture 18C at 9M Bits NRZ is slightly narrower than the eye of Figure C-16, Picture D at 10Mb/s NRZ of the Twist'N'Flat™ cable.

The cable's frequency response at 340 feet, stub 18, is down approximately 1.5Mb/s NRZ since the eye at 7.5Mb/s NRZ is comparable to the Figure C-16, Picture F at 9Mb/s NRZ. The eye is closing at 8Mb/s NRZ and is closed at 8.5Mb/s NRZ.

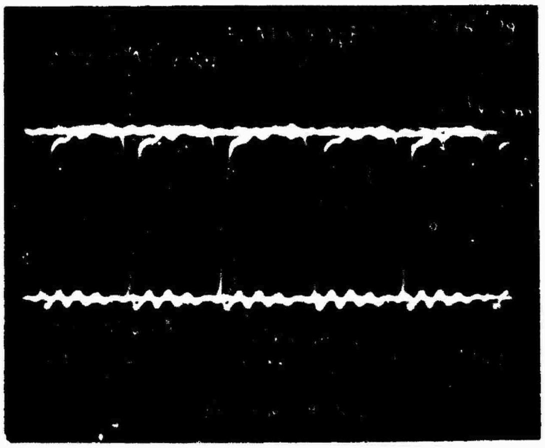
At 400 feet, stub 21, the eye is closing at 5Mb/s NRZ and is closed at 5.5Mb/s NRZ. This compares to Figure C-17, Pictures 3 and F for 7.5Mb/s NRZ closing and 8Mb/s NRZ closed.

The frequency response of this cable is decreased from the Twist'N'Flat™ by 1 to 2.5Mb/s NRZ depending upon the cable length at which the measurement is taken.

1.1.14 Common-mode test with 400-feet Twist'N'Flat™. This test was conducted to determine the effect of a common mode sinewave voltage upon the system. The system common-mode configuration is shown in Figure C-1.

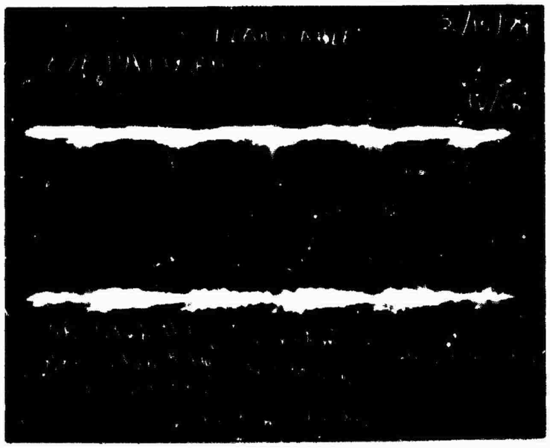


A

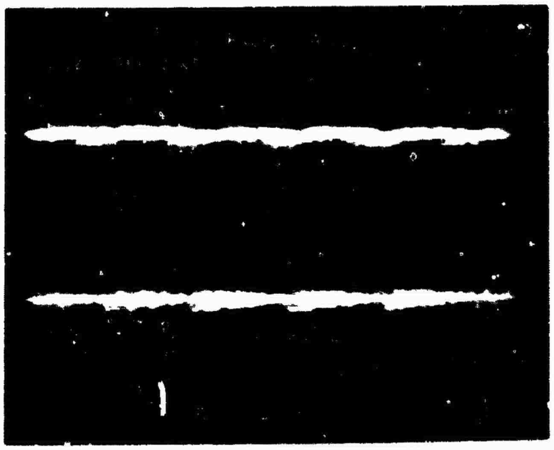


B

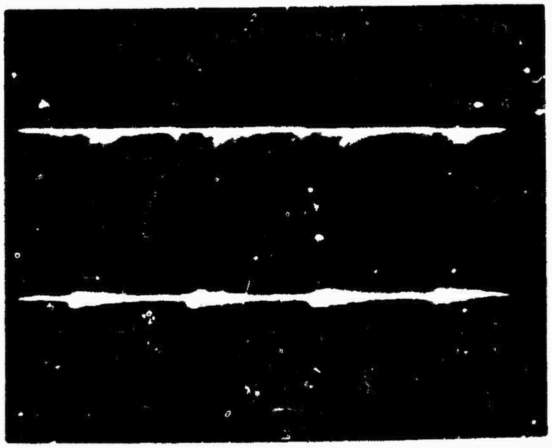
C



D



E



F

Figure C-18. 400-foot Spectra-Zip™ with simulated receivers.

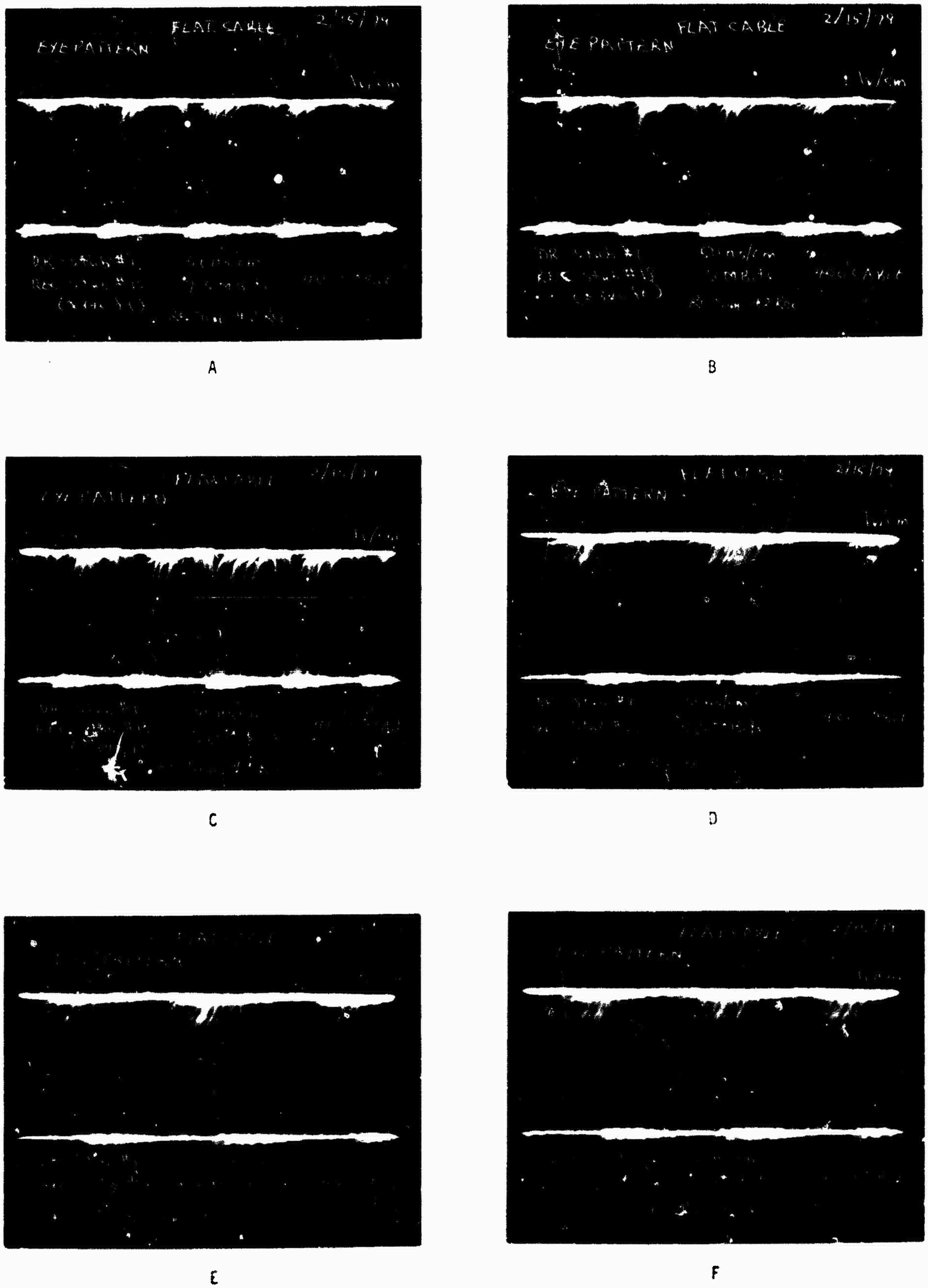


Figure C-19. 400-foot Spectra-ZipTM with simulated receivers.

The first step was to determine whether the common-mode signal by itself was mismatched on the cable's driven twisted pair lines. Two oscilloscope channels were calibrated to display the same amplitude when the scope probes were connected to the scope calibrator signal. Then the function generator and audio oscillator were adjusted so one channel of the oscilloscope displayed a 3v peak-to-peak (3v p-p) 100 kHz sinewave from one of the 51.1 ohm line terminating resistors to single-point ground at the near end (closest to stub 1) of the cable. The other scope channel was connected to the other 51.1 ohm resistor at the same end of the line with respect to the same ground point. With just the cable and 21 stubs with no electronics, there was no discernable mismatch. Then the oscilloscope probes were switched to the two 51.1 ohm resistors at the far end of the 400-foot line (closest to stub 21). the measurement there was 1.6 v p-p because of the line voltage drop, but again there was no discernable mismatch. Then all four wirewrap boards were plugged into the stubs. Each end of the line was measured as previously described. With the power off, there again was no discernable mismatch at either end. With the power on and all 21 drivers in the three-state mode, there was an approximate 10 mv difference between these two waveforms at the near end and the same difference at the far end of the line. So it appeared that the common-mode voltages were very balanced in the system. This suggested that a common-mode signal below the receiver common-mode input voltage range of $\pm$ 15v should have little effect on the system. This was not the case, however, as will be seen in the eye patterns for this test.

Figures C-20 and C-21 show the results of this test. Each half of Pictures 20A and B were taken at opposite ends of the cable with no common-mode signal. The difference in the eye width indicated that the system is not bilateral. The results depend upon which end of the cable is driven. Both ends of the cable need to be checked to find the worst-case frequency response.

The actual common-mode signal is shown in Figure C-20, Picture C. The waveforms were taken at the near end (driver end) of the cable. The top waveform is without the electronics connected to the stubs. Note the clipping of only the negative portion of the common-mode signal after the wire-wrap boards were connected to the stubs. This waveform stayed the same whether the power to the electronics was on or off. All 21 drivers were in the three-state mode. This clipping is caused by the conduction of the substrate diodes in the drivers. This was discussed earlier in the *Line Driver Common-Mode Problem* section.

The other pictures in Figures C-20 and C-21 show the jitter in the eye patterns caused by the common-mode voltage. The amount of jitter was unexpected. This jitter could be caused by several things mentioned earlier. One could be the same problem that causes the driver/receiver system to favor the logic-zero state as discussed in section 1.1.9. Another could be the unbalance that caused the 10 millivolt difference in the common-mode signal when measured with the power on and all drivers in the three-state mode discussed at the beginning of this section. The driver substrate diode conduction with negative common-mode signals could be the reason for the jitter. Further tests need to be conducted to determine what causes the jitter.

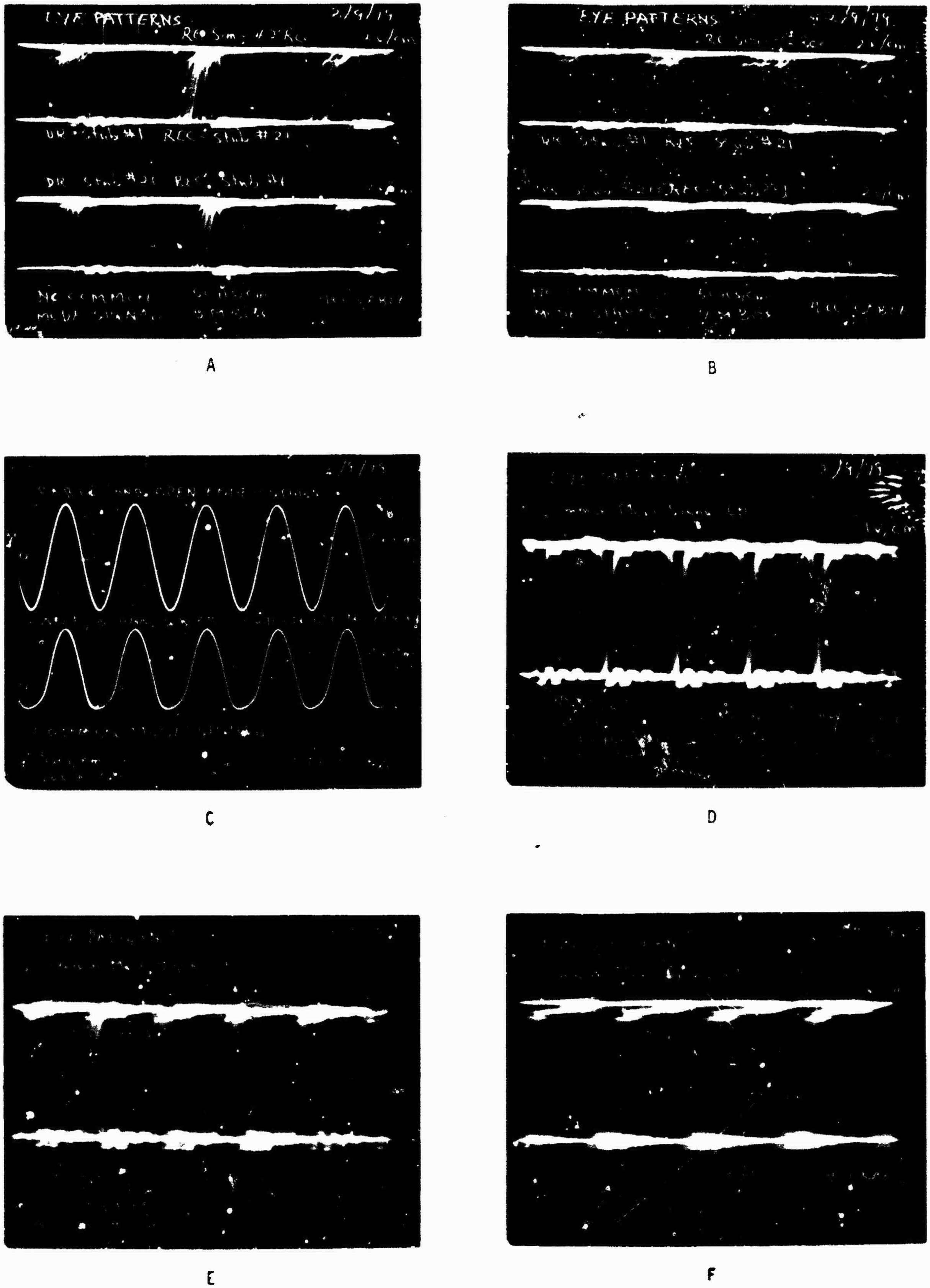
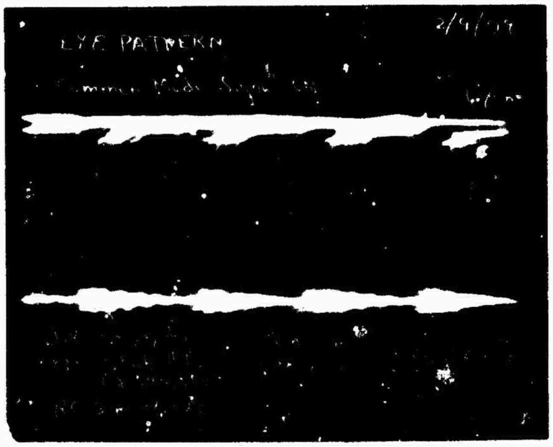
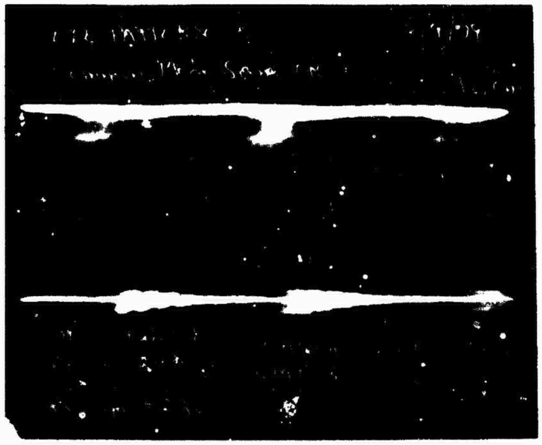


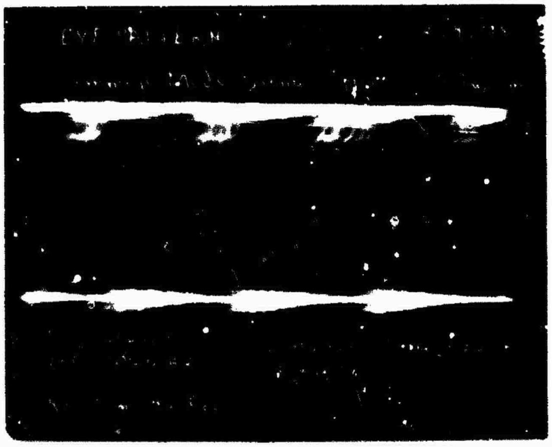
Figure C-20. Common-mode with Twist'N'Flat™.



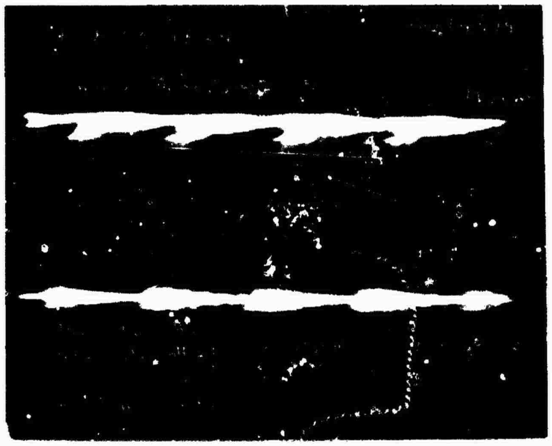
A



B



C



D

Figure C-21. Common-mode with Twist'N'Flat™.

The Figure C-20 and C-21 eye patterns are hard to interpret since the jitter causes faint lines which are difficult to see. The comparisons between these pictures and the corresponding ones without the common-mode signal in Figures C-16 and C-17 are summarized below.

The jitter on the Pictures 20D and E caused the rise and fall waveform width to be about one half again as wide as on the corresponding Pictures 16C and D.

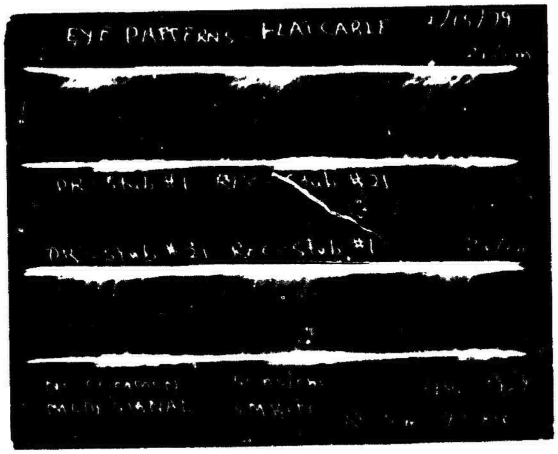
At 340 feet, stub 18, the eye is closing at 8Mb/s NRZ in Picture 21A; whereas the eye is closing at 9Mb/s NRZ in Figure C-16, Picture F.

At 400 feet, stub 21, the eye was closed at 7Mb/s NRZ in Picture 21C; whereas the corresponding closure was at 8Mb/s NRZ in Figure C-17, Picture F.

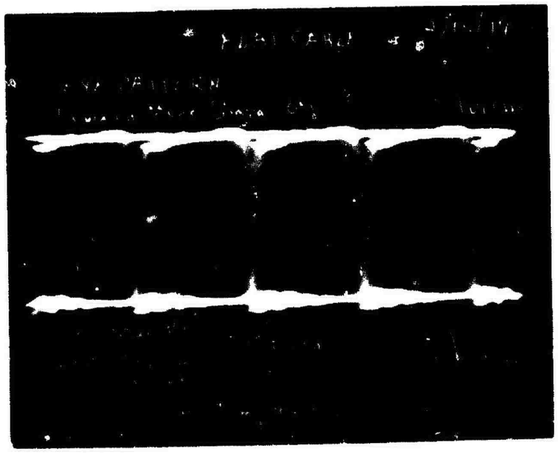
The common-mode signal appeared to decrease the system frequency response approximately 1Mb/s NRZ. The cause of the jitter needs to be found.

1.1.15 Common-mode test with 400-feet Spectra-Zip™. The common-mode voltage signal was adjusted and checked as for the Twist'N'Flat™ cable. Again, it appeared that the common-mode voltages on each of the two lines were very balanced. However, the jitter was even more pronounced for this cable type.

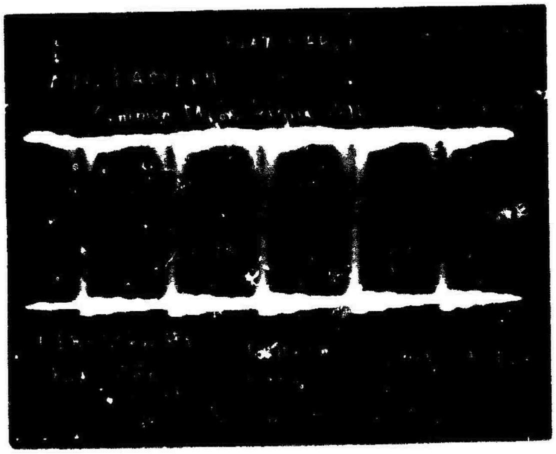
Figure C-22 shows the test results. Picture C-22A was taken for comparison with Figure C-20, Picture A. The eye is much narrower for the Spectra-Zip™ cable. The two waveforms on Picture C-22A again show that the system is not bilateral. However, in this case it appears that the eye is narrower when the driver is on stub 21. This is just the opposite from Figure C-20, Picture A.



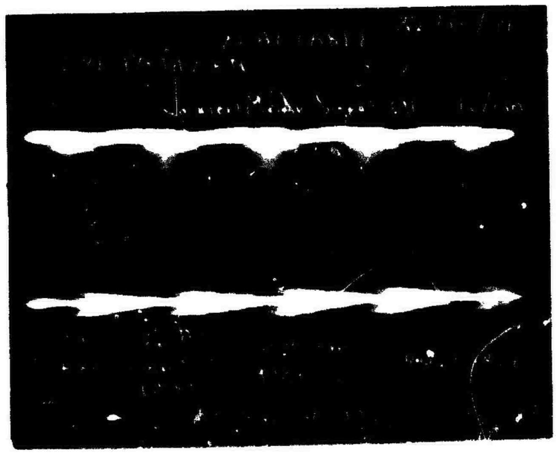
A



B

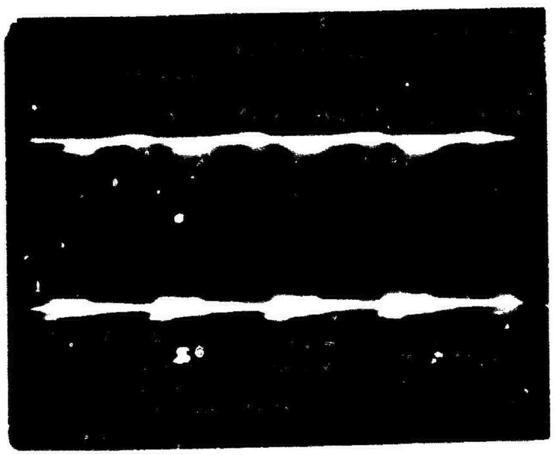


C



D

E



F

Figure C-22. Common-mode with Spectra-Zip™.

The jitter on the eye patterns again causes problems in interpreting the pictures. It can be seen that the results are worse than that of the Twist'N'FlatTM. For example, at 100 feet, stub 6, the eye pattern looks very good at 10Mb/s NRZ on Figure C-20, Picture D for the Twist'N'FlatTM cable. However, the same conditions on Picture 22C shows the eye closing at 10Mb/s NRZ.

At 400 feet, stub 21, the eye was already closed at 5Mb/s NRZ, so this picture was not taken.

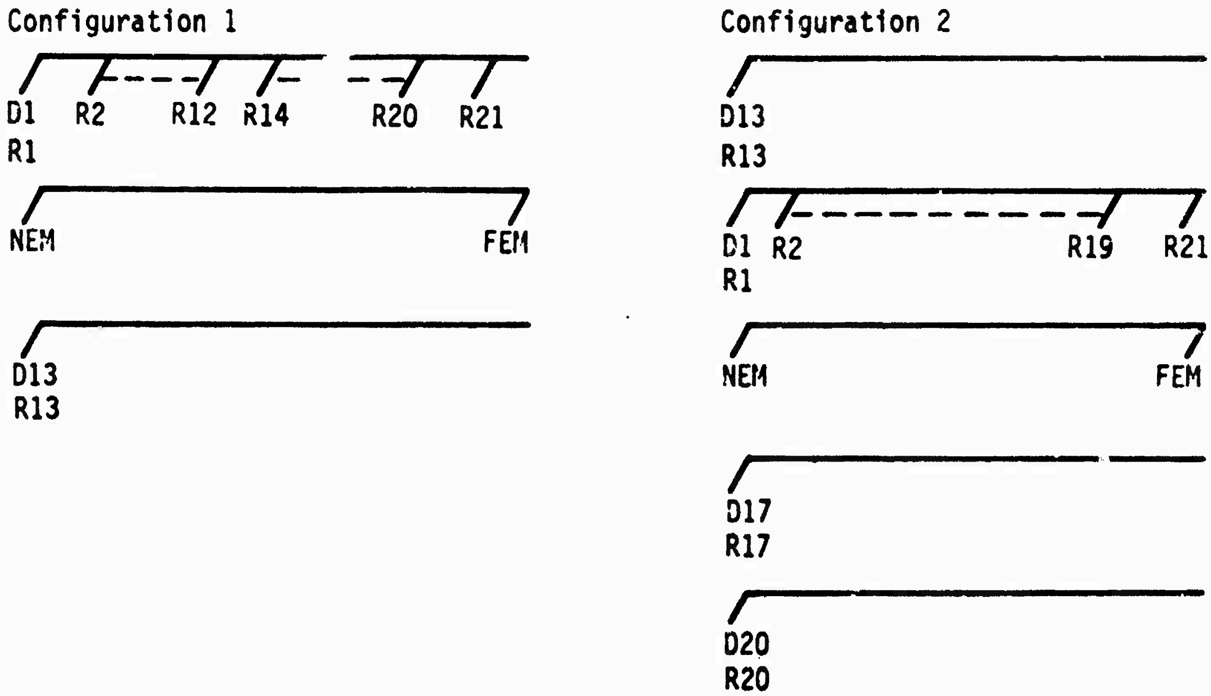
The Spectra-ZipTM is much worse in frequency response deterioration with a common-mode signal than is the Twist'N'FlatTM cable.

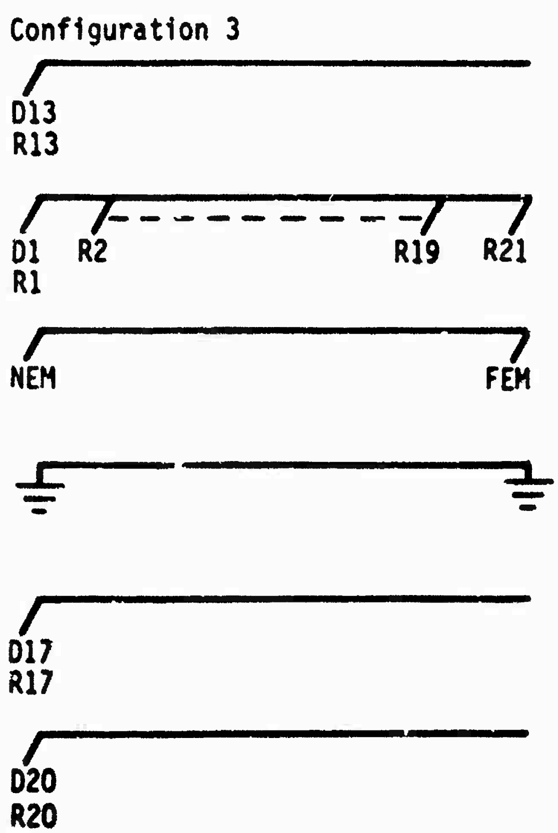
1.1.16 Crosstalk measurements. In order to obtain information on the interaction of signal lines upon adjacent lines, several test types were conducted. Both cable types were tested using three different wiring configurations as shown in Figure C-23. To use drivers for other than the main line driven by driver 1, stubs and their associated driver/receiver pairs were removed from the main line. For example, stubs 13, 17, and 20 are missing from the main line in configurations 2 and 3. These stubs were connected to the other three driven lines.

For configuration 3, a grounded line pair was inserted to ascertain the amount of crosstalk shielding that could be obtained.

The test using configuration 1 was conducted first. The criteria for selecting the frequencies for the measurements were:

a. One picture at 5Mb/s NRZ;
b. Two pictures at frequencies between approximately 5 and 12Mb/s NRZ where the crosstalk was maximum; and
c. One picture at a frequency between approximately 5 and 12Mb/s NRZ where the crosstalk was minimum.





NOTES:

1. Legends
   DXX = Driver XX
   RXX = Receiver XX
   NEM = Near End Measurement
   FEM = Far End Measurement
   = Single Point Ground
2. Each line represents one pair of wires; e.g. one pair of wires are grounded in configuration 3.
3. All lines are terminated at both ends.
4. All drivers except those driving lines are in the three-state mode.
5. NEM and FEM are taken from only one line of the pair with respect to single point ground.

Figure C-23. Crosstalk configurations.

For comparison, the pictures for the other two configurations were then taken at these same frequencies.

All near-end (NE) and far-end (FE) measurements were taken on the 51.1 ohm line terminating resistors at the Line Termination and Single-Point Ground box shown in Figure C-3. The top waveform on the scope pictures was used as a reference. It was taken right at the input to the drivers, all of which were on the same wire wrap board.

1.1.17 Crosstalk test with 400-feet Twist'N'FlatTM. Figures C-24 and C-25 show the single-ended crosstalk waveforms for the three configurations.

With two lines driven as in configuration 1, Figure C-23, the near end maximum voltage is approximately 120 mv p-p. The minimum is approximately 80 mv p-p. The far end voltages are approximately 90 mv p-p maximum and 40 mv p-p minimum.

With four lines driven as in configuration 2, Figure C-23, the waveforms and amplitudes at the four frequencies are almost identical to the corresponding pictures with only two lines driven.

The configuration 3 pictures with the four lines driven and one grounded show considerable decrease in near end voltage (except at 11.4Mb/s NRZ) compared to configuration 2. However, the far end voltage increased except at 11.4 Mb/s NRZ where it decreased slightly.

Based upon these pictures, the lines directly adjacent to the measured line as in configuration 1, induced almost all the crosstalk. The grounded line, configuration 3, results were inconclusive. However, in general, this ground-line reduced the near-end voltage and increased the far-end voltage. Additional measurements, probably differential instead of single ended, and bit-error rate tests with crosstalk and data on the same lines should be performed.

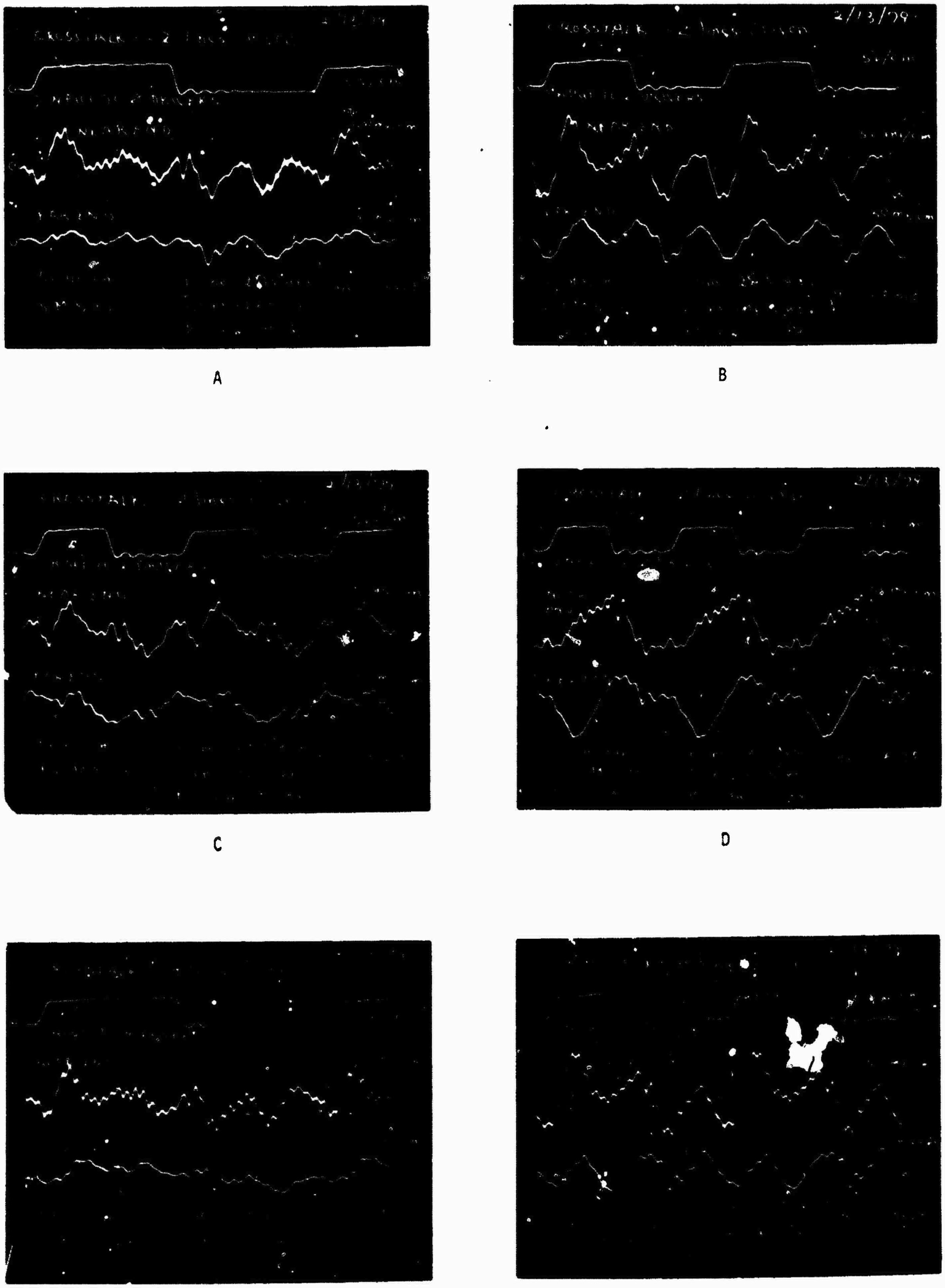
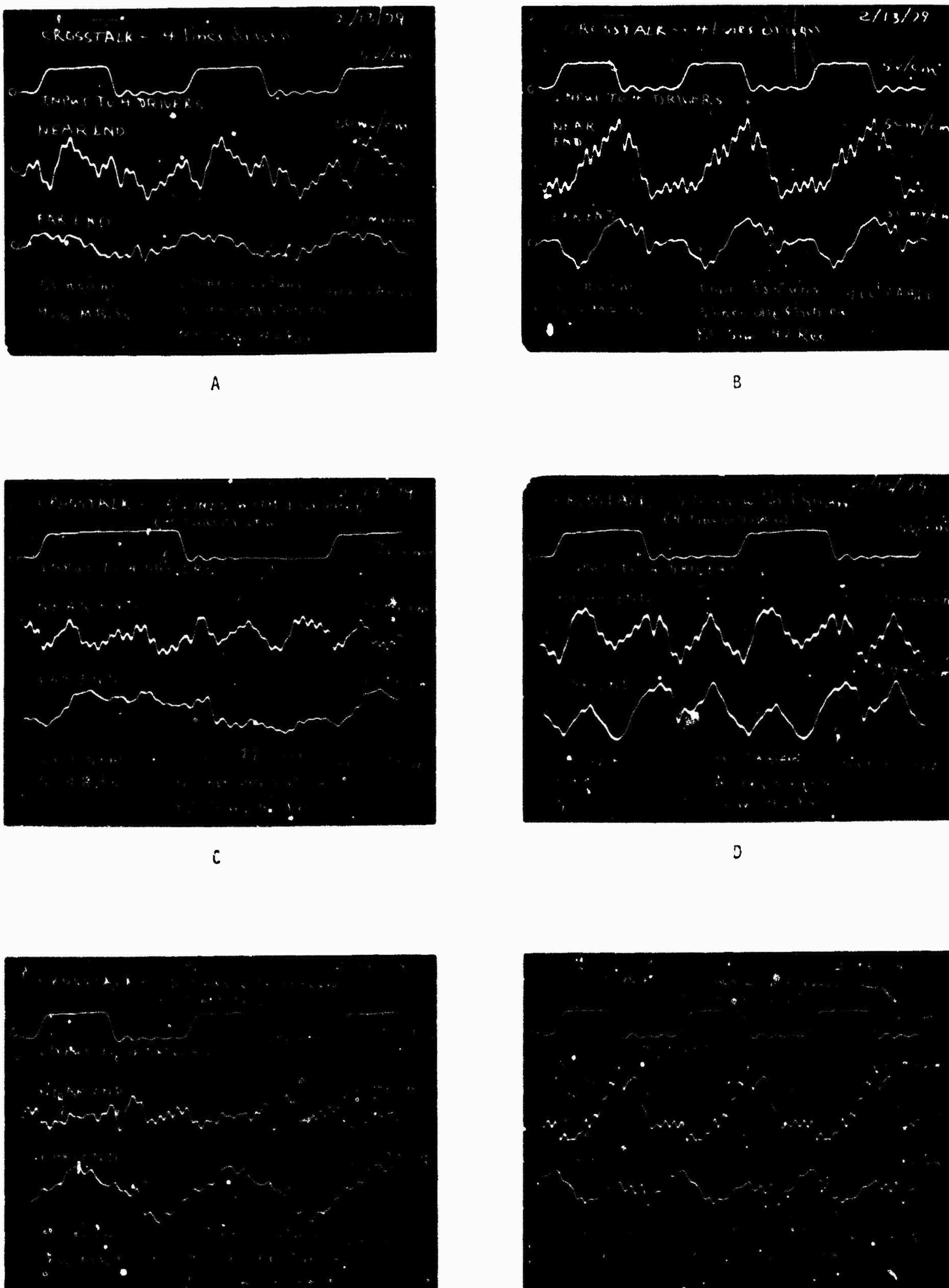


Figure C-24. Crosstalk with Twist'N'Flat™.



A B C D E F

Figure C-25. Crosstalk with Twist'N'Flat™.

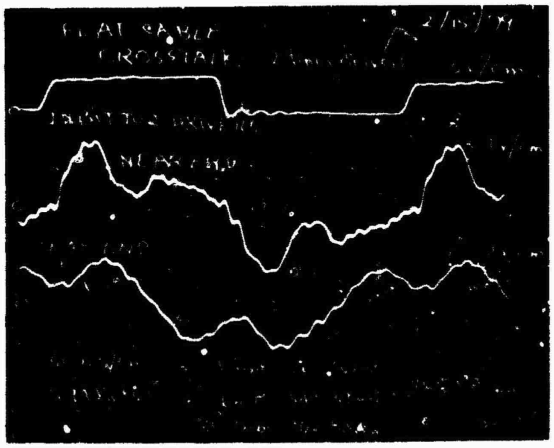
1.1.18 Cross talk test with 400-feet Spectra-Zip™. The Spectra-Zip™ cable showed more crosstalk amplitude than on the Twist'N'Flat™. Figures C-26 and C-27 show the single-ended crosstalk waveforms for the three configurations.

The pictures with two lines driven, Figure C-26, A through D, show the near-end maximum voltage approximately 270 mv p-p. The minimum is approximately 170 mv p-p. The far-end voltages are approximately 200 mv p-p maximum and 80 mv p-p minimum. This is double the crosstalk voltage observed for the Twist'N'Flat™ cable.

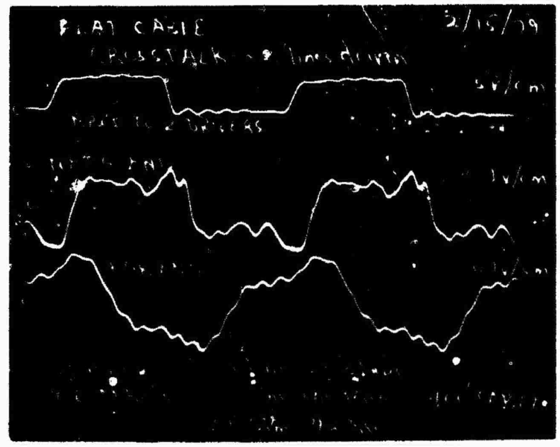
Note that with four lines driven, the amplitudes on the four pictures are about the same as the corresponding pictures with only two lines driven. Unlike the Twist'N'Flat™ cable results, the corresponding waveforms between the Spectra-Zip™ configuration 1 and 2 pictures are not nearly identical.

With the four lines driven, fifth grounded configuration, the crosstalk waveform seemed to be smoothed. This is shown in the Figure C-27, Pictures C through F. This did not happen in the corresponding Twist'N'Flat™ test. The grounded-line pair has more effect on the crosstalk in the Spectra-Zip™ cable. It appears to isolate the driven lines from the measured line. The differences in amplitude between these and the corresponding pictures for only four lines driven do not correlate.

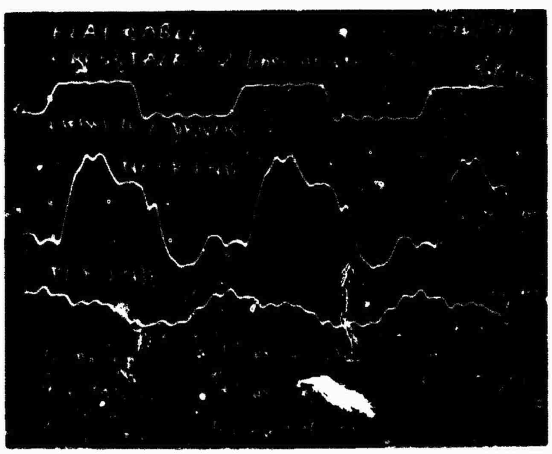
These test results show that the crosstalk is approximately doubled over the results using the Twist'N'Flat™ cable. Both tests showed that the two most adjacent lines to the one being measured induce almost all the crosstalk. The grounded-line pair has much more isolation effect in the Spectra-Zip™ cable than in the Twist'N'Flat™.



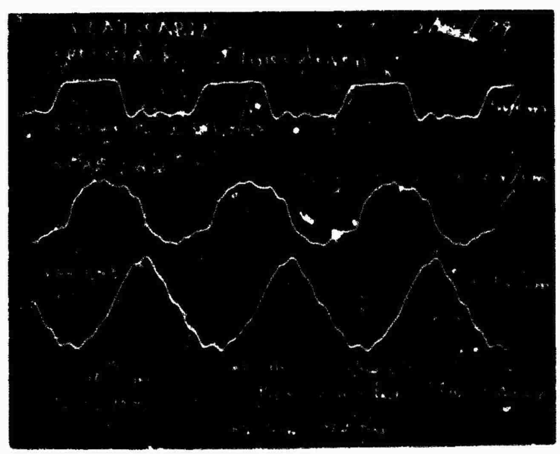
A



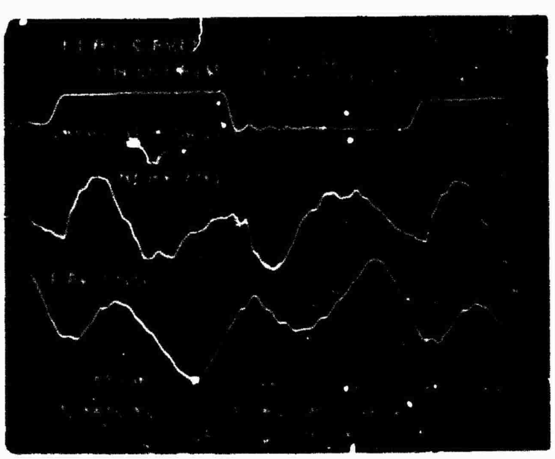
B



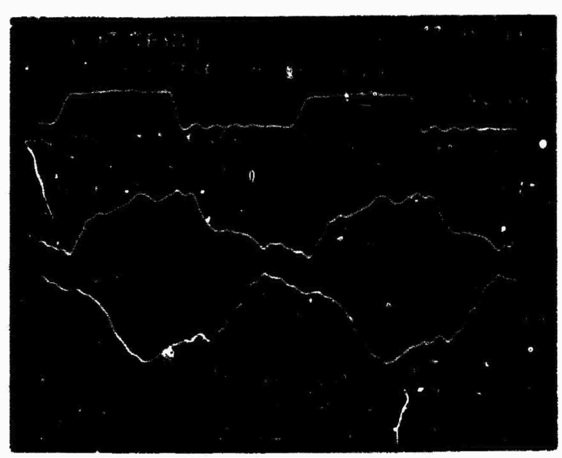
C



D

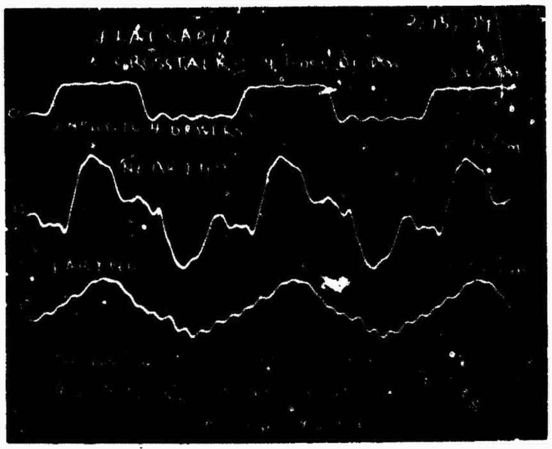


E

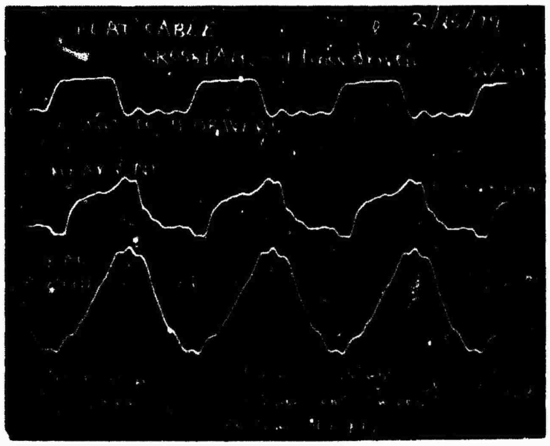


F

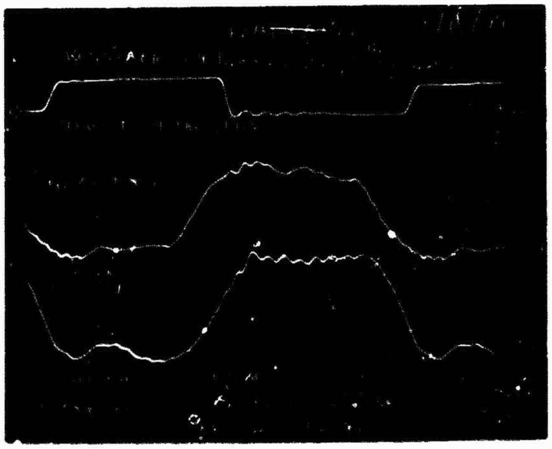
Figure C-26. Crosstalk with Spectra-Zip™.



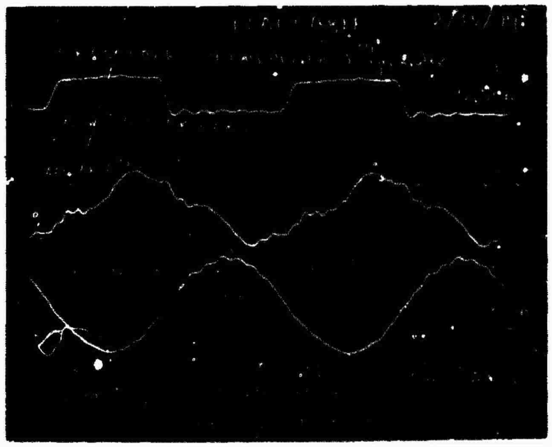
A



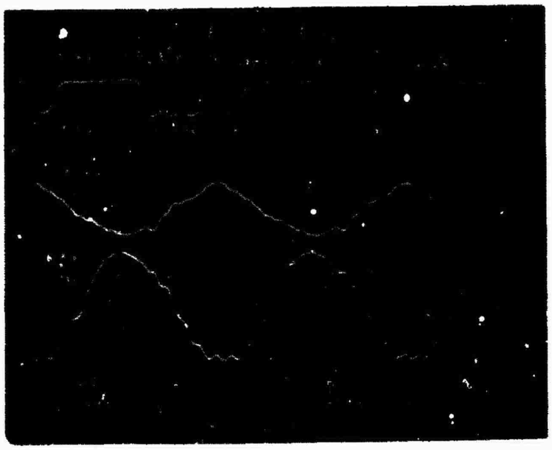
B



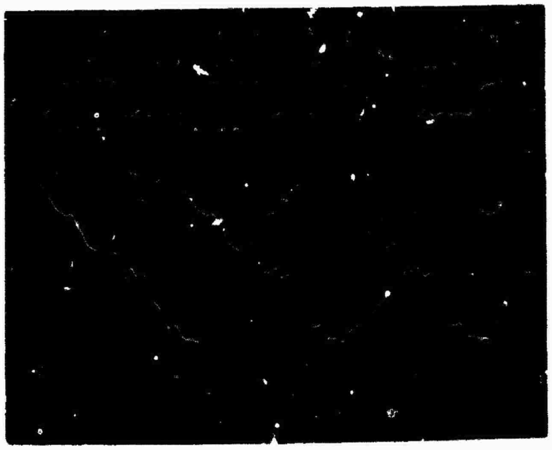
C



D



E



F

Figure C-27. Crosstalk with Spectra-Zip™.

1.1.19 Conclusions and recommendations. The Twist'N'Flat™ cable is far superior to the Spectra-Zip™ for this application. The Twist'N'Flat™ has better frequency response, both with and without common-mode signals; and the amount of crosstalk induced is much less. So the remainder of this section will concern itself with only the Twist'N'Flat™ cable.

At 100 feet, using 21 receivers, this cable easily carries 10Mb/s NRZ data. With 21 receivers on the 400-foot cable, 10Mb/s NRZ is still good at 340 feet according to the eye pattern, and decreases to about 9Mb/s NRZ at 400 feet.

The results of the receiver simulation tests, which uses 21 actual receivers and 42 simulated ones, show that the 10Mb/s NRZ eye pattern is still good at 300 feet. This decreases approximately 9Mb/s NRZ at 340 feet and 7M b/s NRZ at 400 feet.

With the common-mode voltage on the simulated receiver configuration, the 10Mb/s NRZ eye pattern still looked good at 300 feet. However, the frequency response at 340 and 400 feet decreased to approximately 8Mb/s NRZ and between 5 and 7Mb/s NRZ respectively.

Several important items were discovered in the process of planning for and conducting this test.

a. The existing three-state line drivers have a negative common-mode voltage failure problem. New-type line drivers are required for data bus applications.
b. The system response is not bilateral. At minimum, both cable ends should be driven to determine worst-case frequency response.
c. The terminating resistors should be ac coupled to ground with large value capacitors to eliminate any line driver dc offset problems.
d. To obtain maximum noise immunity and to perhaps eliminate some of the common-mode jitter seen in those tests, the line driver/receiver configuration should be balanced so that the optimum receiver threshold occurs in the center of the eye pattern.

Many more tests need to be conducted to complement the data already obtained and to solve some of the problems encountered. After ac coupling the terminating resistors and solving the problem of balancing the driver/receiver for optimum receiver threshold in the eye pattern center, the following tests, at a minimum, need to be conducted.

a. Bit-Error Rate (BER) measurements need to be made with the system to determine the maximum frequency response of different configurations. These measurements should be conducted both with and without common-mode noise simulation, and also with other lines driven with different data patterns to determine the effect of crosstalk on the system BER.

b. The problem of why the common-mode signal creates a large amount of jitter in the eye pattern must be solved. Several possible causes were suggested in the report.

c. More crosstalk data must be obtained. Differential measurements between the two measured lines are needed to determine the actual effect upon the differential input to the receiver.

Though there are some unresolved problems, the Twist'N'Flat™ cable met expectations. The test results confirm that this cable will perform adequately as the intrashelter data bus.

REFERENCES

1. The Interface Handbook, 1975, Fairchild Semiconductor.

2. The Line Driver and Line Receiver Data Book, 1977, Texas Instruments.

APPENDIX C-1
TELECON

Motorola Phoenix, Arizona (602) 244-3716 Dusty Morris 1 February 1979

1. Subject: Line Driver turn-on with negative common-mode noise.

If a negative voltage is placed on the output of a driver that is in the high-impedance (HiZ) mode, and this voltage is negative more than approximately - 1 v, parasitic diodes between the substrate and the driver output turn on. There is no current limiting for these parasitic diodes, and heavy currents can flow. This not only causes undefined driver states, but also tends to degrade the bond wires and integrated circuits, either of which could eventually burn out. This situation is also possible if the *ground* on one driver is negative (due to common mode noise on the ground line) with respect to other driver's grounds. When this *negative ground* driver is ON and others are in the HiZ mode, this negative voltage can be put on the bus line via the ON driver output sink transistor to the HiZ driver outputs. This causes the same substrate diode conduction.

Turning off the +5v dc power to the HiZ drivers does not help since the parasitic diodes still turn on.

The new party-line spec, *designated RSaaa at this point* being written will eventually require a new party-line driver using either single +5v dc or ±5v dc power; but this driver is at least a year away.

2. Subject: Split resistor termination

The two resistors to ground is not the optimum configuration for terminating the line. This is because the line drivers have some dc offset, and the path to ground takes power from the drivers. Connect this center tap of the two resistors through a large value capacitor to ground thus eliminating the offset problem.

TELECON

T.I. Dallas Texas Dale Pippenger 1 February 1979
(214) 238-5908

1. Subject: What is input capacitance of Line Receiver 75115N?
Each input to ground is approximately 3 pf.
The maximum is approximately 5 pf. This parameter is not specified.

2. Subject: Problem with line driver turn-on with negative common-mode noise.

Pippenger said essentially what Dusty Morris from Motorola stated. The substrate diode between the collector of the output drive circuitry and the substrate conducts with the negative spikes of common-mode voltage. This causes junction heating and the diode becomes leaky and degrades over a period of time. This could eventually cause driver failure.

He thinks the new future party line driver will have dual supplies connecting the substrate to the negative supply voltage.

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